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SOLAR HOT WATER FOR MONTANA

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SOLAR HOT WATER WORKSHOPS

MAY-JUNE 1984

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
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MONTANA
SOLAR
HOT WATER

GENERAL GUIDELINES AND RULES OF THUMB FOR SDHW SYSTEMS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

GENERAL GUIDELINES & RULES OF THUMB FOR SDHW SYSTEMS

Siting & Orientation

1. True south in Montana is 14° to 21° east of Magnetic south, depending on the location (e.g., Missoula is 20° east and Miles City is 15° east).

2. Solar collectors should be oriented within 30° east or west of true south. At 30° off true south, the annual average system performance (output) will be about 5 percent less than that for true south. Orientation east of south will allow the system to begin collecting solar energy earlier in the morning.

3. Solar collectors should be tilted at an angle of latitude ± 10°. Latitudes for Montana range from 45° to 49°. The steeper tilt angles (55° to 60°) bias the collection of solar energy toward the winter (due to low sun angles and ground/snow reflection) and assist the collectors in shedding snow.

4. Solar collectors should not be shaded more than 5 percent by surrounding trees, buildings, etc. from 9 a.m. to 3 p.m. Mountain Standard Time.

Sizing & Performance

1. The consumption of hot water in a typical residence is 15 to 20 gallons per person per day.

2. The annual energy consumption for domestic water heating in a residence is 25 to 50 percent of the total annual energy consumption in the residence, depending on the number of occupants, the type of heating systems, the insulation levels in the residence, etc.

3. A solar design method, such as F-Chart, should be used in conjunction with actual measured solar radiation values for the location in question to size a SDHW system and predict the energy savings.

4. SDHW systems are generally sized to reduce annual hot water energy use by 50 to 80 percent and generally require 50 to 100 square feet of solar collector area. Both the savings and area depend on a number of factors.

5. Liquid-based SDHW systms are generally more efficient than air-based systems due to higher pump and heat exchanger efficiencies and higher fluid thermal conductivities and heat capacities.

6. Liquid-based SDHW systems generally convert 25 to 50 percent of the solar radiation strikinging on the collectors into useful, delivered heat. The actual efficiency of any system depends on factors such as collector type, design and installation, pipe and tank insulation levels, and control operation.

7. The energy consumed by pumps and controls ("parasitic" energy) in a liquid-based SDHW system is generally 2 to 4 percent of the energy collected by the solar collectors. In other words, the system has a Collection Coefficient of Performance of 25 to 50.

Design & Installation

1. The performance, energy savings, and lifetime of a SDHW system are directly related to the design and installation of the system.

2. Select and install SDHW systems for maximum performance, reliability, durability, and safety, and for minimum homeowner maintenance and adjustments.

3. Follow all applicable plumbing, electrical, and other codes.

4. Use hot water conservation measures in conjunction with the SDHW system.

5. In Montana, a SDHW system must be freeze-protected to $-40^{o}F$.

6. Provide isolation valves and unions so that the SDHW system can be serviced. Valves, unions, controls, instruments, etc., must be accessible.

7. Provide at least basic monitoring equipment such as thermometers, flow meters, pressure gauges, etc., so that system problems can be identified as soon as they occur.

Solar Collectors & Mounting

1. Solar collector materials and mounting systems must be able to withstand extremes in temperature, precipitation, and wind.

2. Roof-mounted solar collectors and mounting systems must be securely tied into the roof rafters and be able to withstand winds of 100 mph.

3. Considerations of shading, snow shedding, glare, clearance for drainage, and aesthetics should be made prior to mounting collectors.

4. Mounting systems should not have different metals in direct contact and roof penetrations should be flashed and sealed. Wood used in mounting systems should be redwood or cedar, or it should be pressure-treated and suitable for exterior use.

5. Collector flow rates for liquid-based systems should be 0.03 to 0.07 gpm per square feet of collector (lower values for water and higher values for oil transfer fluids). In air-based systems, the flow rate should be 2 to 4 cfm air per square feet of collector.

6. The flow of fluid through each collector in an array should be balanced. The temperature rise across a liquid-based collector under operation should be in the range of 5^{o} to $25^{o}F$.

Storage Tanks

1. Storage tanks and back-up water heaters should be insulated to a minimum of R-15.

2. The maximum temperature of SDHW systems must be considered when selecting suitable materials for storage tanks.

3. Each storage tank and water heater must have a pressure/temperature relief valve, and the outlet of the valve must be piped to within 6 inches of the floor.

4. Single-tank SDHW systems should be used only when the heat exchanger is a thermosiphon exchanger or a coil-in-tank in the bottom of the tank and the electric back-up heating element is in the top of the tank.

5. In double-tank systems, the solar storage tank must be plumbed in series with the back-up water heater. Cold water must enter the solar storage tank first. A valved manifold connecting the two tanks should be used so that either or both tanks can be isolated for maintenance or for operation in different modes.

6. Tanks should be installed in mechanical rooms equipped with floor drains. Tanks installed above living areas must be equipped with a catch pan piped to a drain.

Controls & Wiring

1. Ground the collector array and control circuit to prevent injury to occupants and the control equipment.

2. Mount controls to minimize damage from heat and vibration.

3. Sensors must be correctly located, thermally bonded, and insulated.

4. The control and pump should be on a separate electrical circuit and protected through the use of a fused switch box.

5. When possible, provide redundant freeze protection and high storage temperature switches or sensors wired in series.

6. Wiring must be neat, secure, and weatherproof and must be installed according to the electrical codes.

Heat Exchangers

1. Correct heat exchanger sizing, fluid flow rates, and arrangement of piping are critical to the performance of the SDHW system.

2. Factors that increase heat exchanger performance and capacity include the following: transfer fluids with high thermal conductivities and heat capacities; high fluid flow rates and turbulence at the heat-transfer surface; clean transfer surfaces; a large transfer area; a transfer surface with high thermal conductivity (metal); counter (opposite) flow of transfer fluids; and a large temperature difference between transfer fluids.

3. In liquid-based SDHW systems, the heat exchanger should be sized to provide 0.05 to 0.30 square feet of heat-exchange surface area per square feet of collector area. The lower end of this range is appropriate for forced circulation external counter-flow heat exchangers with special heat-transfer surfaces. The upper end of the range is appropriate for internal coil-in-tank exchangers that use oils as a heat-transfer fluid.

4. The sizing methods and recommendations provided by heat exchanger manufacturers should be followed.

5. Heat exchangers must be accessible and removable for cleaning, maintenance, and replacement.

6. Double-walled exchangers with leak detection must be used to separate potable water from nonpotable solar heat-transfer fluids. Double-walled exchangers generally transfer 20 to 40 percent less heat than single-wall exchangers operating under the same conditions.

7. Internal coil-in-tank exchangers shold be placed in the bottom of the tank to take advantage of temperature stratirication.

8. Preferred heat exchanger materials are copper, copper-nickel alloys, and stainless steel. Mixed metals (such as copper and steel) should not be used in exchangers.

9. Heat exchangers can be connected in series and/or installed parallel to achieve the desired heat-transfer capacity. The flow rates and pressure drops through the exchangers depend on the type of connection made.

Pumps

1. Pumps typically used in SDHW systems are centrifugal pumps in the 1.40 to 1.10 horsepower range. These pumps are capable of providing heads of up to 30 feet of water or flow rates of up to 25 gallons per minute.

2. Pumps with stainless steel or bronze "wetted" parts must be used in open systems that contain oxygen to minimize rust and corrosion. Cast iron pump parts may be used in closed, oxygen-free systems.

3. A centrifugal pump can provide either a high head or a high flow rate, but not both. Pump head is inversely related to flow rate. Pumps are generally tested with water, and a "pump curve" showing the relation of head and flow rate is developed. The pump curve will be different for fluids other than water.

4. A pump will run most efficiently at conditions in the middle of the pump curve.

5. Pumps can be staged in series or in parallel to increase pump head or flow rate, respectively.

6. Pumps for drain-back SDHW systems are generally high-head, low-flow pumps. They must be located at least 1 1/2 feet below operating water level of the drain tank.

7. Pumps should be equipped with a suction strainer/filter and check valves. Flow meters, flow adjusting valves, etc., should be located after the pump discharge.

Piping & Ducting

1. Plumbing and ducting runs should be as short, neat, and unobtrusive as possible. Runs through unheated spaces and exterior walls should be minimized.

2. Liquid-based solar collector loops should generally be constructed of 1/2" or 3/4" Type L hard-drawn copper tubing, wrought copper fittings, and 95-5 tin-antimony or tin-silver solder.

3. Copper tube must be sized to hold a fluid flow velocity in the range 4 to 6 feet per second to minimize erosion, pressure drop, and pumping energy. Copper tube ends should always be reamed prior to soldering.

4. All solar and hot water lines must be fully insulated and exterior lines should be sealed, and weatherproofed. Piping in interior heated spaces should be insulated to a minimum of R-4 and in exterior and unheated spaces insulated to a minimum R-7.

5. Copper tube must be supported at least every 8 feet horizontally and at least every 10 feet vertically. Pipe supports should be thermally isolated from solar and hot water lines. Straight runs of copper tube over 75 feet must be provided with an expansion loop or joint.

6. Do not mix metals in piping loops or networks. Always use a dielectric union when making a transition from steel to copper, especially at storage tanks and water heaters.

7. Solar collector supply and return plumbing should always be sloped a minimum of 1/8" per foot of pipe run so that transfer fluid can drain (normal operation in drain-down and drain-back systems and for maintenance in closed-loop antifreeze systems).

Special System Components

1. Always install a hot water tempering valve with the SDHW system to prevent scalding when solar tank temperatures reach 160° to 190°F.

2. Closed-loop antifreeze collector loops must be protected with an expansion tank and pressure relief valve.

3. Closed-loop antifreeze systems and air-based systems must have a check valve and back-draft damper, respectively, to prevent reverse thermosiphoning at night and subsequent freezing of the heat exchanger.

4. When the pressure in the domestic water supply is greater than 80 psi, install a pressure reducing regulator valve.

5. Provide boiler drain valves for each tank and at the low point in piping runs.

6. Seals, gaskets, and seats must be compatible with the fluid contacting them so that they do not dissolve or degrade over time.

Completion of the SDHW System

1. Complete a system checklist prior to system start-up.

2. Pressure test all piping with compressed air and apply soap solution to piping joints to locate leaks.

3. Flush the piping systems with the fluid that will be used in the piping. Do not flush a collector loop with water if it will contain a heat-transfer oil.

4. Test the operation of the controls, sensors, freeze/high-limit switches, etc., with a control tester and/or a volt-ohm meter. Follow the control manufacturer's check-out procedure.

5. Label valves, tanks, piping, special components, etc., and explain their operation and maintenance to the homeowner. Seal off and clearly label piping containing nonpotable fluids. Make the system as "idiot-proof," child-proof, and fail-safe as possible.

6. Provide the homeowner with a homeowner's guide containing instructions, drawings, equipment specifications, warranties, etc.

7. Visit the SDHW system at least once a year for a checkup and maintenance.

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MONTANA
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COMPARISON OF SOLAR DHW SYSTEMS

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Capitol Station
Helena, MT 59620

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GENERAL COMPARISON OF TYPES OF SDHW SYSTEMS

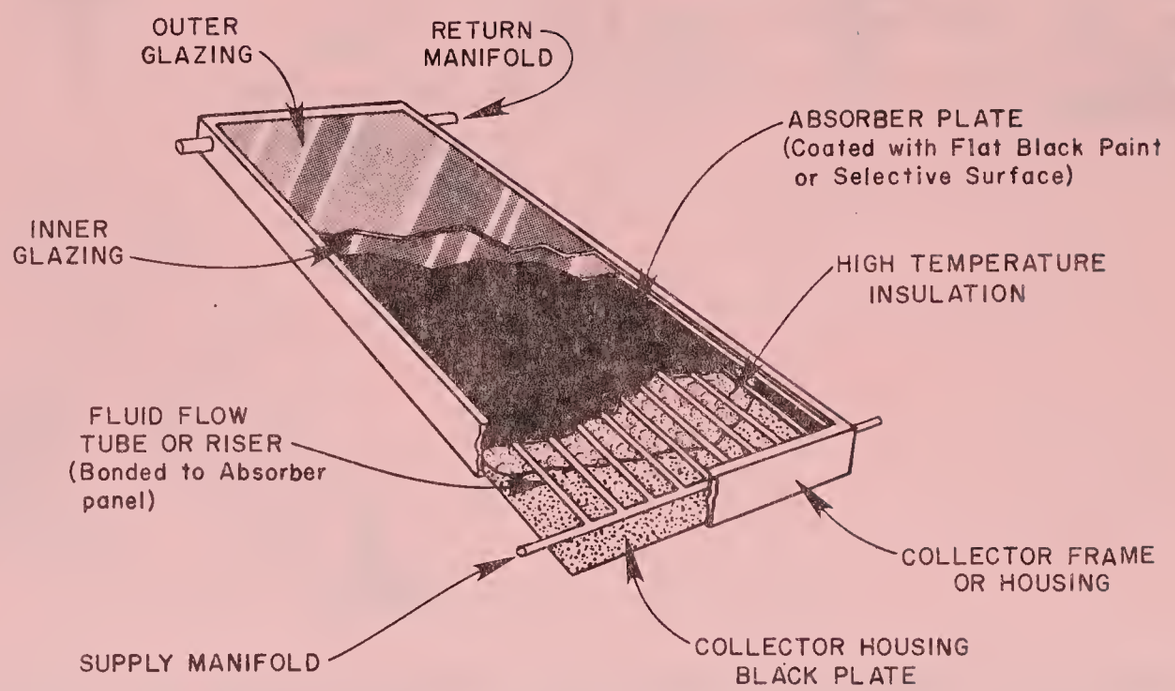
Type of System	Advantages	Disadvantages
Batch/Integral Passive Heater/Thermosiphon (Water-Based)	Water is non-toxic & has good heat transfer properties. System does not require pump, control, or heat exchanger. No parasitic energy use. Operates with low inputs of solar energy.	Freeze-protection is difficult, especially exterior piping. Water in collector loses heat at night. Oxygen and minerals in potable water may cause corrosion & scaling. Pressurized potable water above living spaces has high potential for damage if leaks develop. Use of system may be seasonal & may need to be drained during severe winter conditions.
Drain-Down (Water-Based) (Pumped Circulation)	Water is non-toxic & has good heat transfer properties. Pumped circulation in collectors gives high heat transfer. System does not have heat exchanger. Freezing and night heat losses eliminated by automatic draining of collectors.	System loses water to the sewer each time it drains. Oxygen and minerals in potable water may cause corrosion & scaling. Pressurized potable water above living spaces has high potential for damage if leaks develop. Freeze-protection is dependent on a mechanical drain-down valve; correct use of controls, sensors, and vacuum breakers; and sloped-to-drain collectors and piping.

Type of System	Advantages	Disadvantages
Open-Loop Drain-Back (Water-Based) (Pumped Circulation)	Water is non-toxic & has good heat transfer properties. Pumped circulation in collectors & heat exchanger gives high heat transfer. Separate drain-back tank eliminates potable water from collectors & reduces potential leak damage. Freezing & night heat losses eliminated by automatic draining of collectors.	System requires drain-back tank, heat exchanger, pump, and control. Freeze-protection is dependent on correct use of controls, sensors, and vacuum breakers and on sloped-to-drain collectors and piping. Each drain cycle introduces oxygen into system and increases potential for corrosion. System may require high head pump and increased pump horsepower.
Phase-Change, Refrigerant-Charged, Thermosiphon Collector Loop	Collector loop is freeze-protected by refrigerant. Collector loop is closed from oxygen & potential corrosion is very low. Collector loop does not require pump or control. System operates with low input of solar energy.	Collector loop uses freon refrigerant which requires special care and skill in installing piping and charging system. Freon is linked with reduction of ozone in the atmosphere. The freon-to-water heat exchanger in some systems is located at the top of collector (exterior) and may be difficult to protect from freezing. With potable water connections & tanks located above living spaces, there is potential for damage if leaks develop. Use of the system may be seasonal & the water side of the system may need to be drained during severe winter conditions.

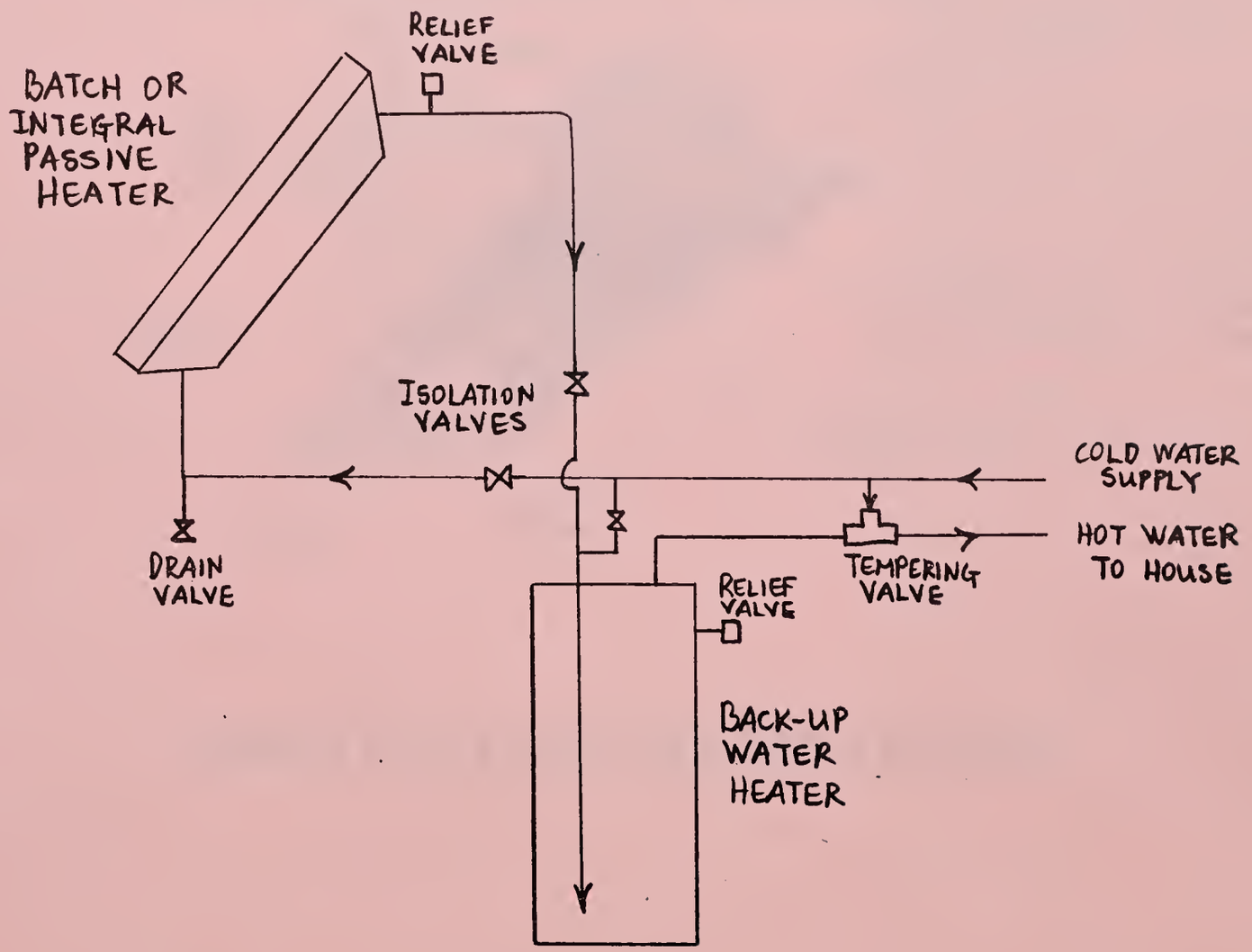
Type of System	Advantages	Disadvantages
Air-Based, Forced Circulation	Air is non-toxic & generally non-corrosive. Air does not freeze or boil. Air will not cause physical damage if a leak in the ducting occurs.	The collector loop ducting runs are difficult to seal against leakage. Air has poor heat transfer properties. Air ducting is bulky and more difficult to install than copper tubing. Performance curves for air collectors are generally lower than for liquid sytems. Air fans/blowers generally consume more power than liquid pumps. A tight back-draft damper is required to prevent heat exchanger freeze-up.
Closed-Loop Pressurized Drain-Back (Water-Based) (Pumped Circulation)	Water in non-toxic & has good heat transfer properties. Pumped circulation in collectors & heat exchanger gives high transfer. Separate closed drain-back tank eliminates potable water and oxygen from collectors & reduces potential leak damage & corrosion. Freezing & night heat losses eliminated by automatic draining of collectors.	System requires drain-back tank, heat exchanger, pump, and control. Freeze protection is dependent on correct use of controls and sensors and on sloped-to-drain collectors and piping. System may require high head pump and increased pump horsepower.

Type of System	Advantages	Disadvantages
Closed-Loop Antifreeze (Pump Circulation)	Freeze-protection is complete with correct antifreeze. Pumped circulation in collectors gives good heat transfer. Solar collector loop is free of oxygen. Solar collector loop can generally use low horsepower pump. System can be used when a water drainage-type of system will not work.	Antifreeze fluids generally have poorer heat transfer properties than water and may require higher pumping rates and larger heat exchanger areas. System requires expansion tank, heat exchanger, pump, control, and plumbing specialties. Antifreezes are non-potable & generally require double-wall heat exchangers. Antifreeze may need to be changed periodically to avoid corrosion. Collector loop is always full of fluid which loses heat at night and may lead to expansion and degradation problems when collectors are stagnant.

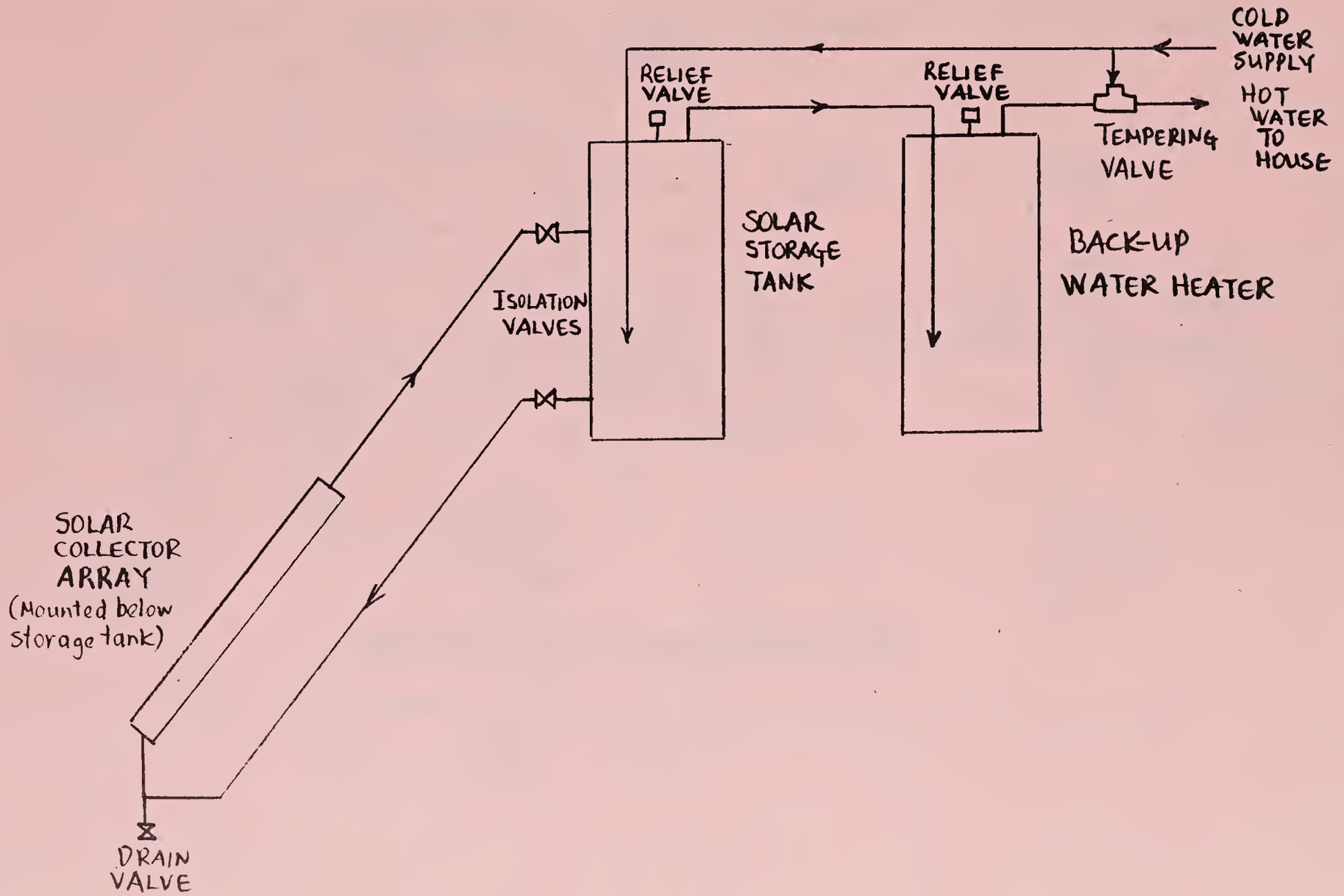
TYPICAL FLAT-PLATE COLLECTOR


OUTER GLAZING
RETURN MANIFOLD
ABSORBER PLATE (Coated with Flat Black Paint or Selective Surface)
INNER GLAZING
HIGH TEMPERATURE INSULATION
FLUID FLOW TUBE OR RISER (Bonded to Absorber panel)
COLLECTOR FRAME OR HOUSING
SUPPLY MANIFOLD
COLLECTOR HOUSING BLACK PLATE

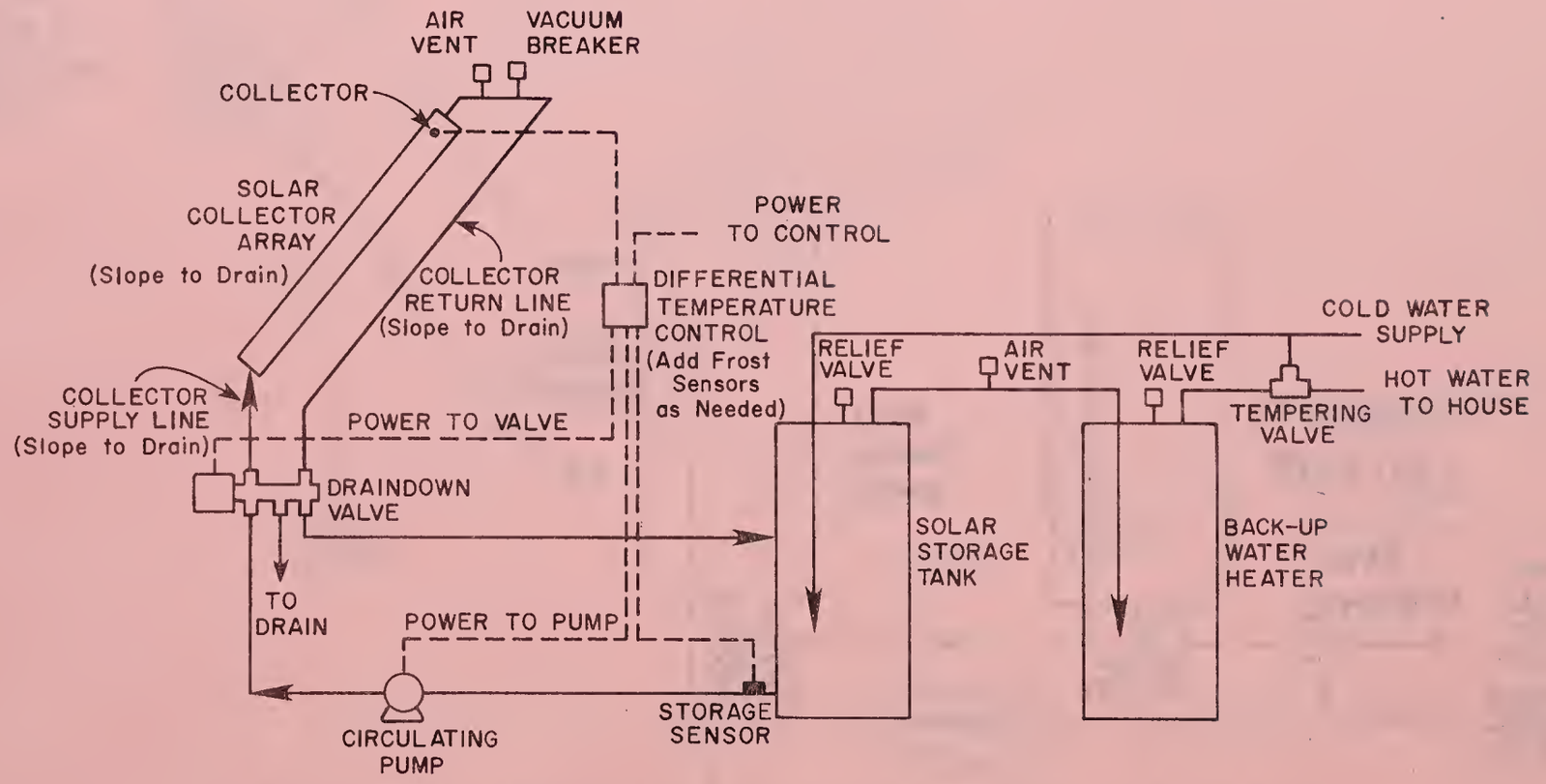
BATCH OR INTEGRAL PASSIVE SDHW SYSTEM



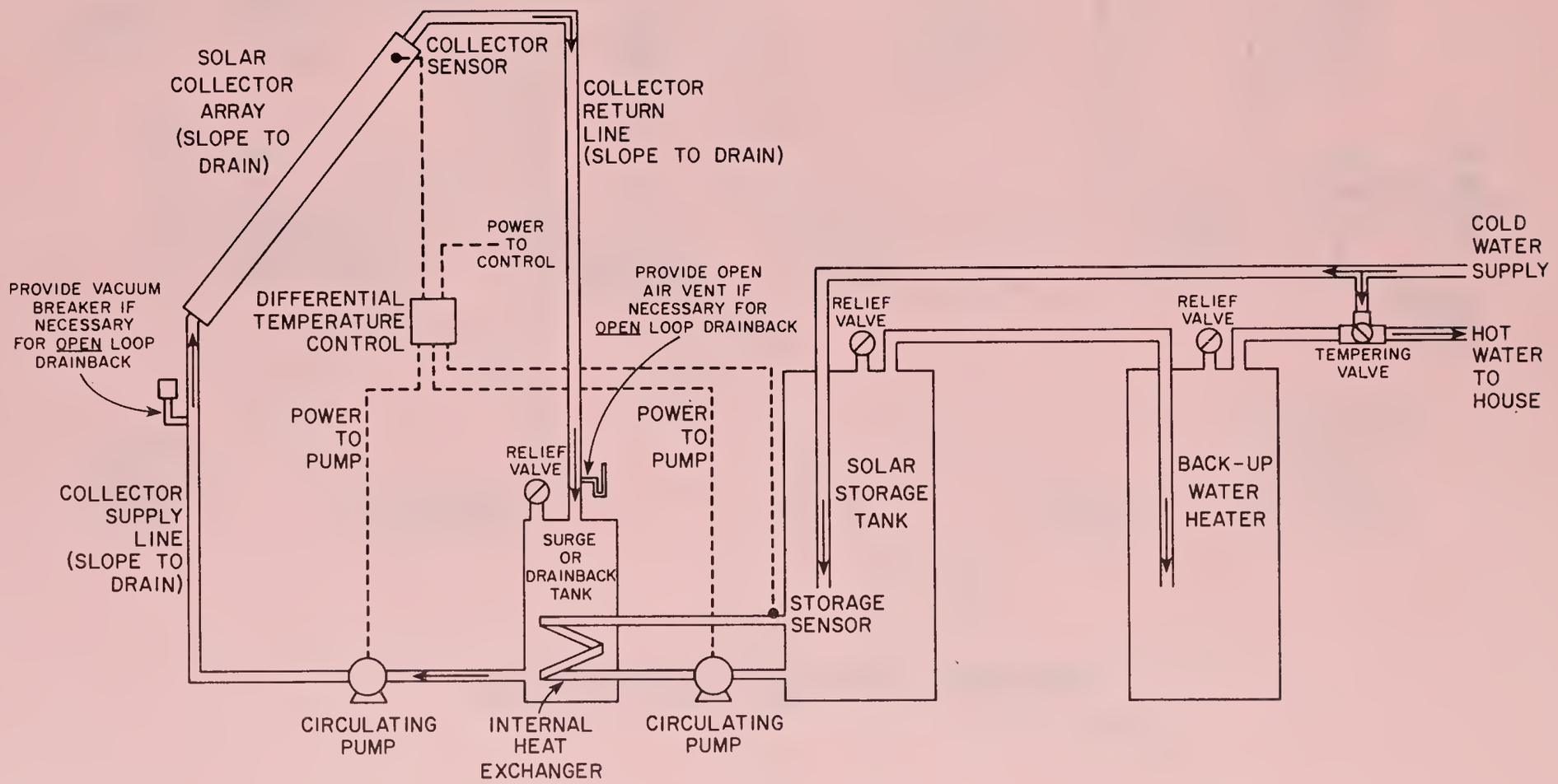
WATER THERMOSIPHON SDHW SYSTEM



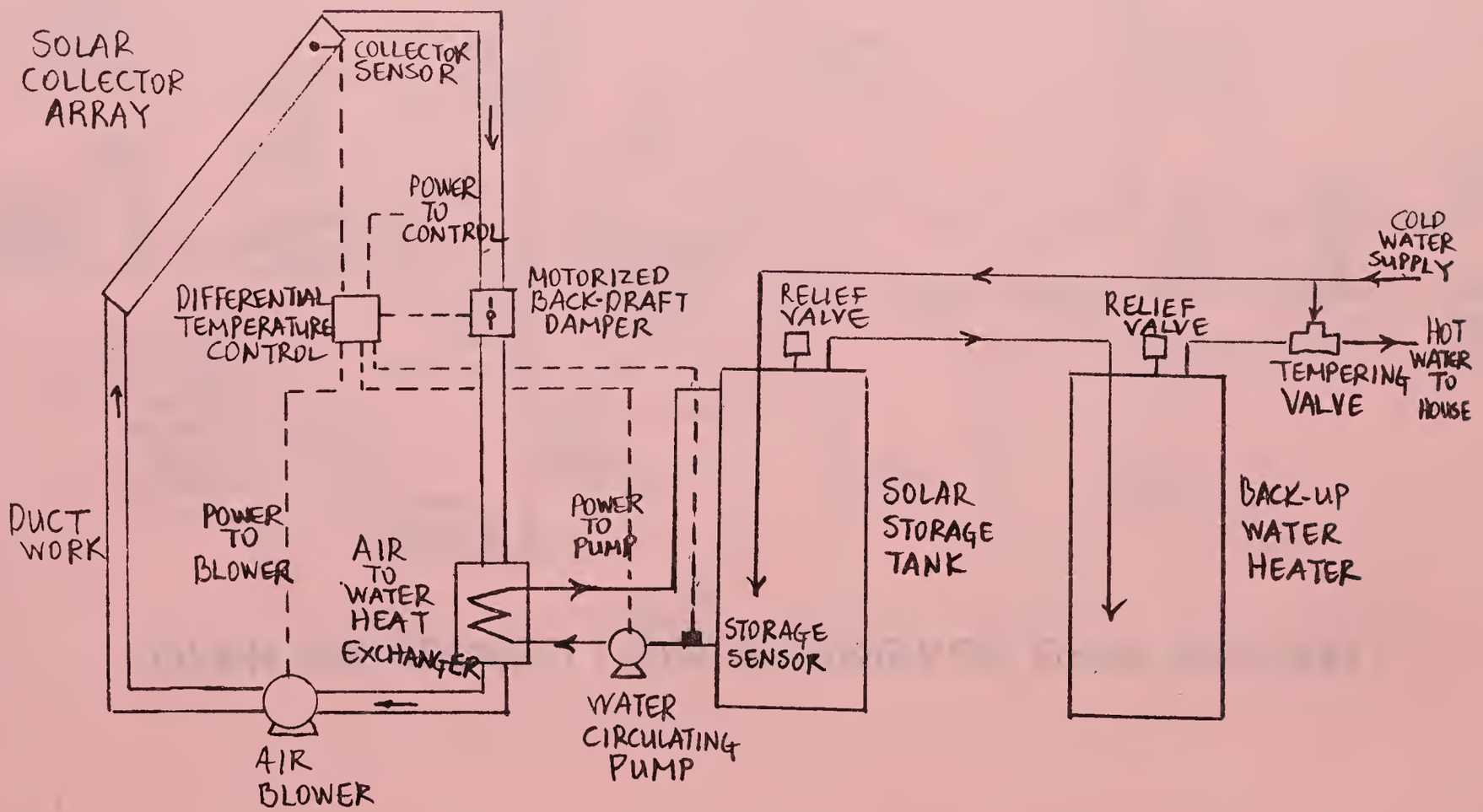
DRAINDOWN DHW SYSTEM



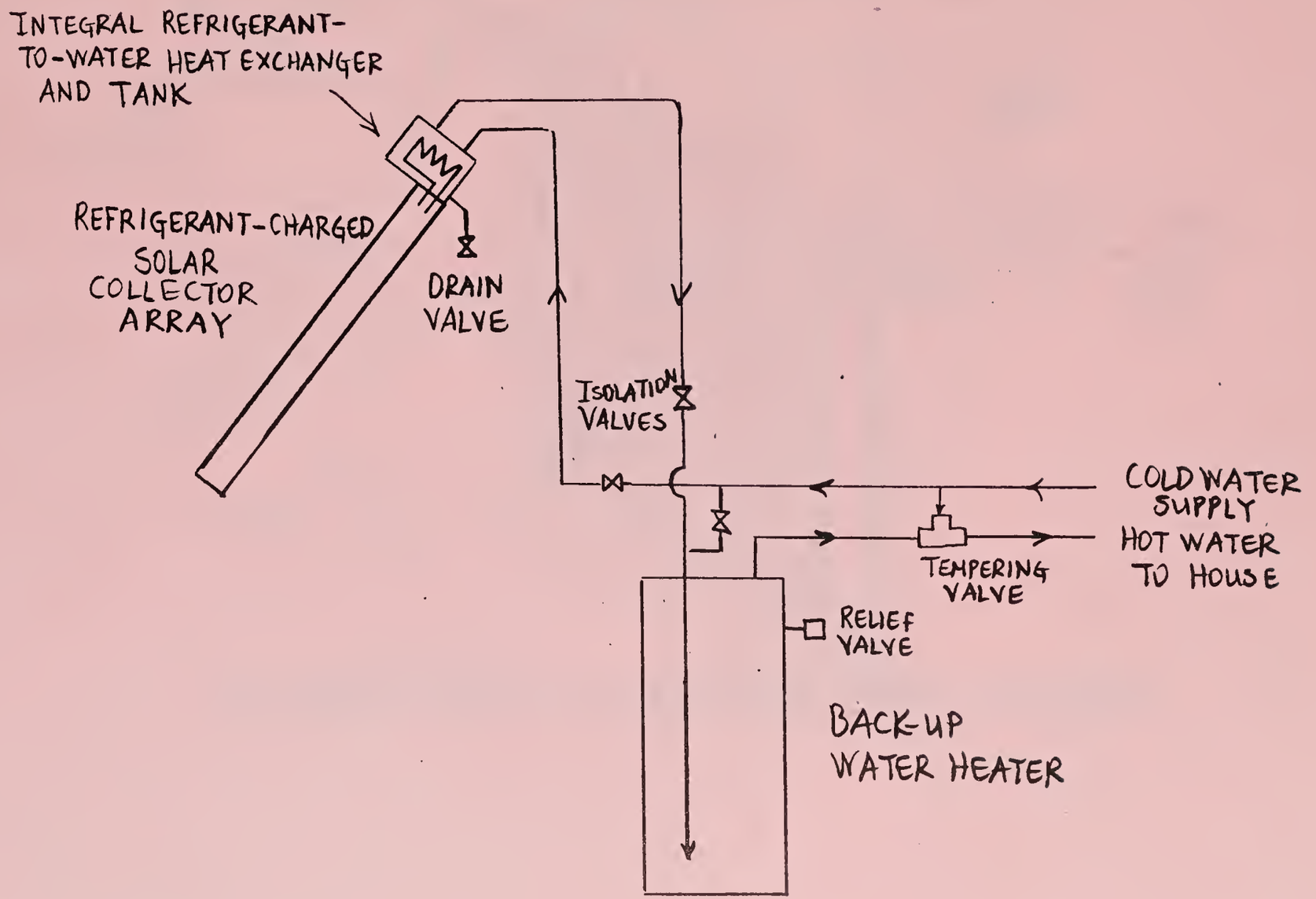
OPEN OR CLOSED LOOP DRAINBACK DHW SYSTEM



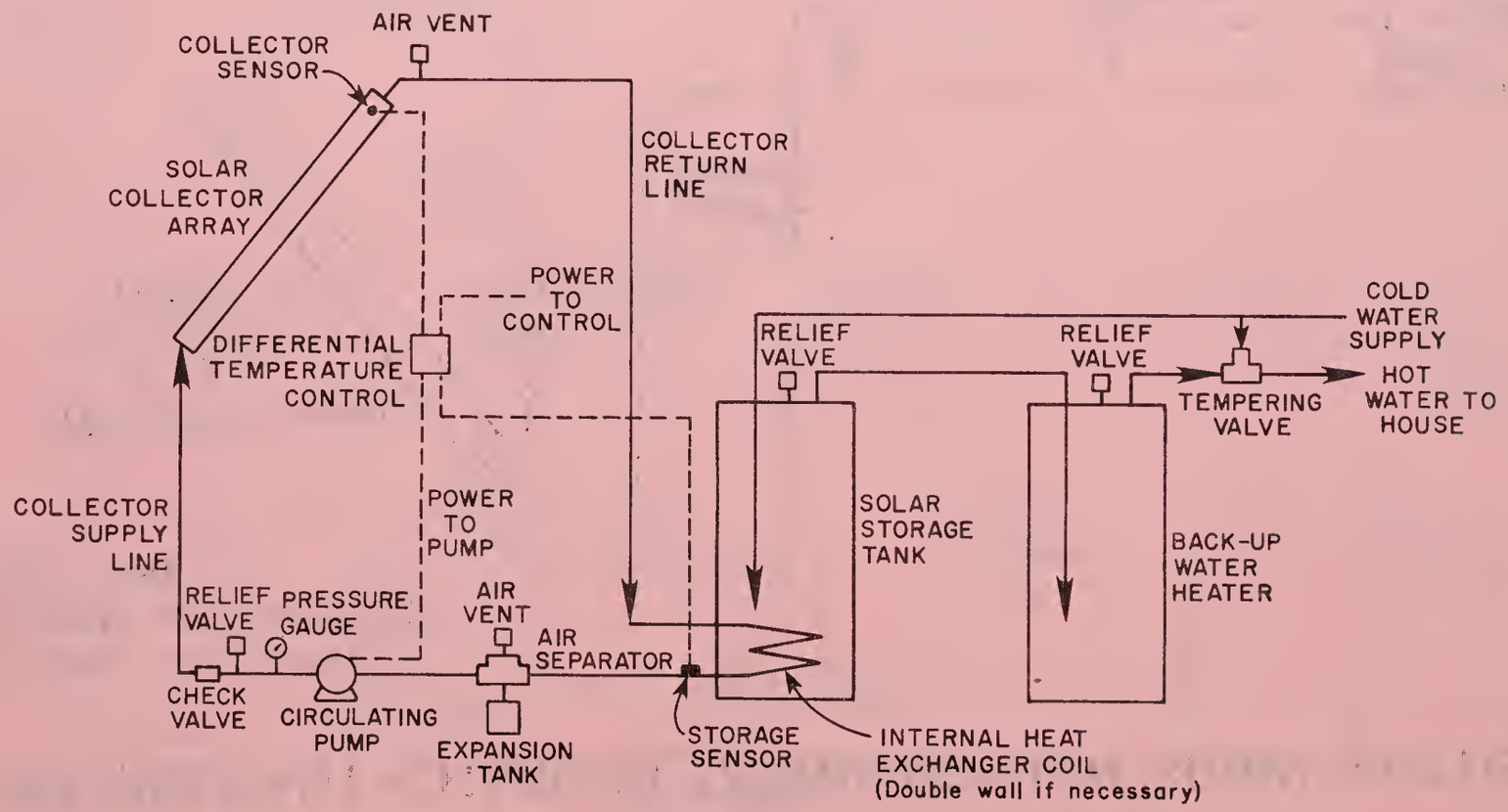
AIR-BASED SDHW SYSTEM



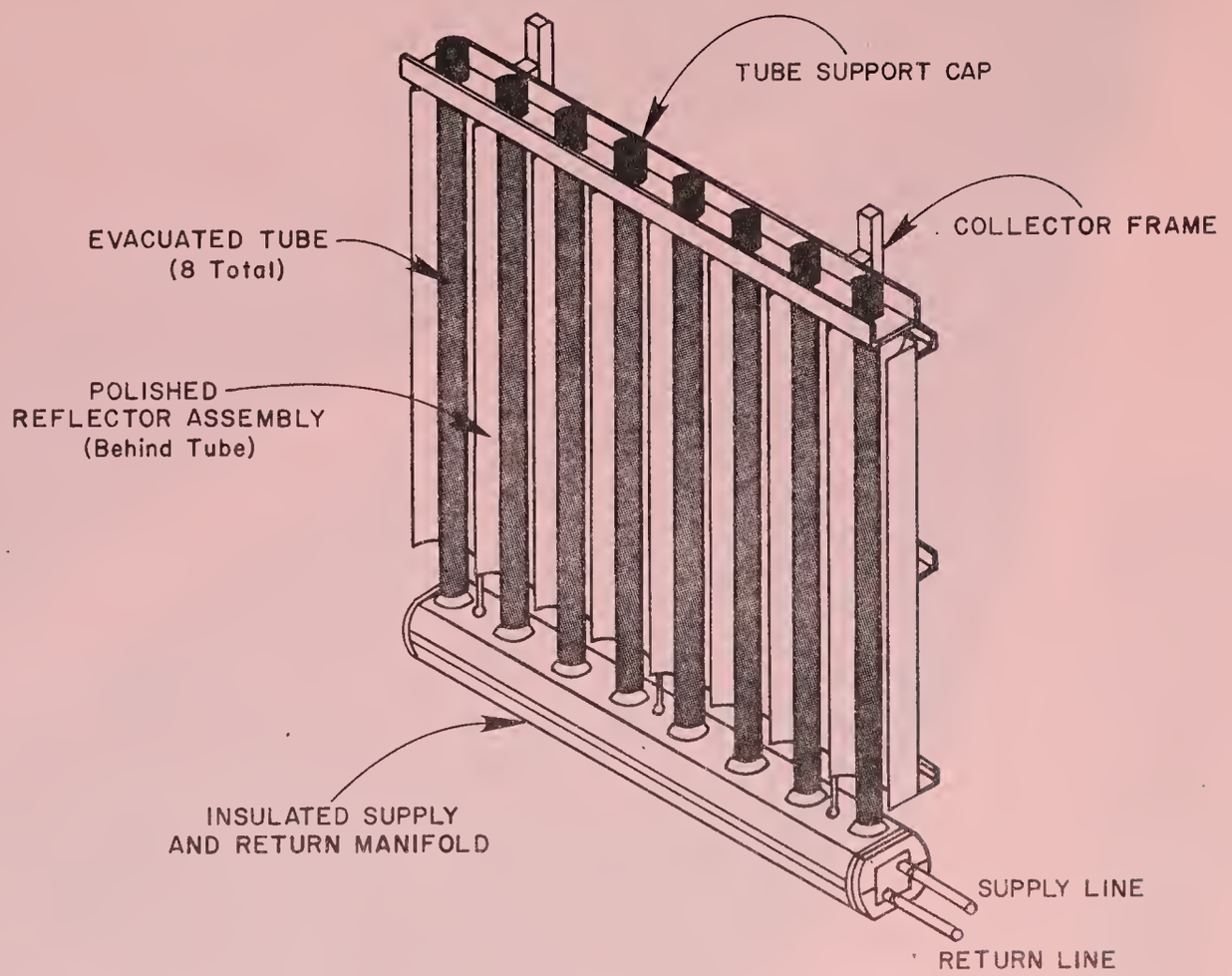
REFRIGERANT-CHARGED THERMOSIPHON SDHW SYSTEM



CLOSED LOOP ANTIFREEZE DHW SYSTEM



EVACUATED TUBE COLLECTOR



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Copper Brass Bronze
Design Handbook

SOLAR ENERGY SYSTEMS

COPPER DEVELOPMENT ASSOCIATION INC.

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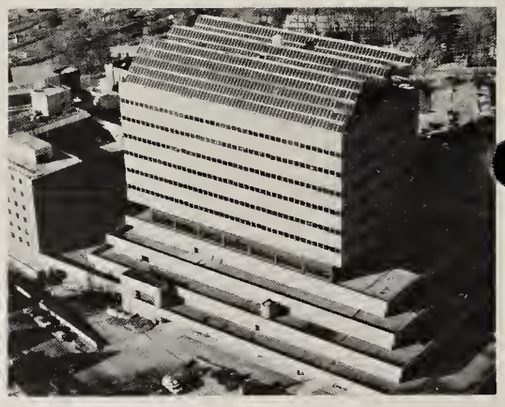
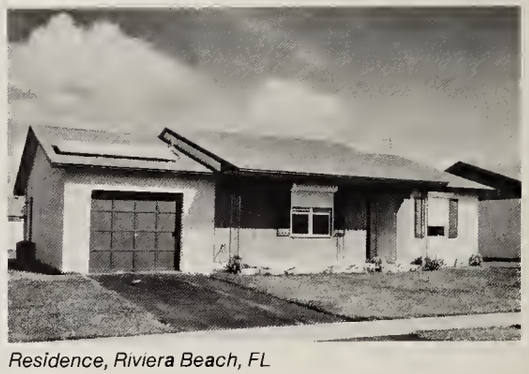


Hospital, Danbury, CT



Residence, Riviera Beach, FL

Residence, Guilford, CT

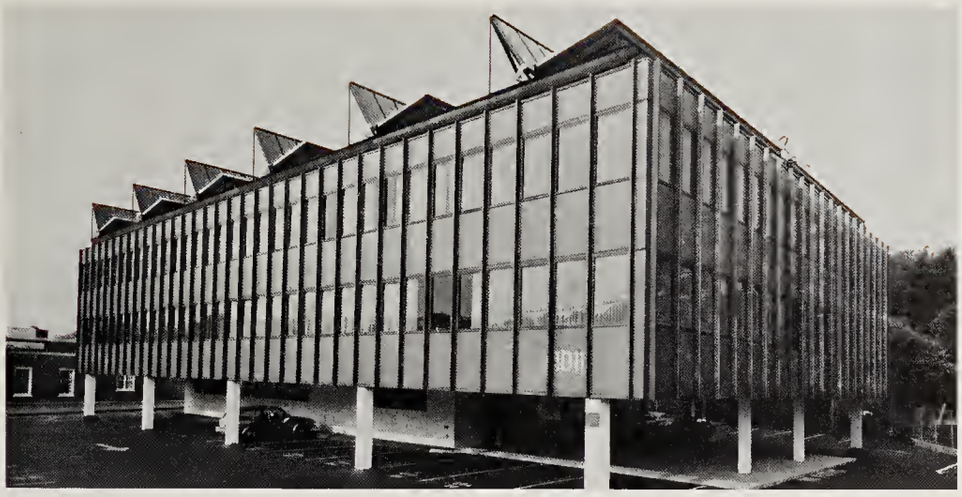
Residence, Breckenridge, CO

This handbook outlines procedures for calculating energy collected from a solar energy system and suggests different alternatives for collection, storage and distribution. Each solar system must be engineered to meet the particular circumstances of its use, and Copper Development Association Inc. assumes no responsibility or liability of any kind in connection with the calculations or system designs set forth herein or their use by any person or organization, and makes no representations or warranties of any kind.

Burt Hill Kosar Rittelmann Associates assisted in the preparation of this CDA Design Handbook.

COPPER BRASS BRONZE DESIGN HANDBOOK

SOLAR ENERGY SYSTEMS



Office Building, Stamford, CT

INTRODUCTION

Most of the energy used presently to keep buildings warm and to heat water for domestic purposes comes indirectly from the sun. The fossil fuels, coal, gas and oil, burned in our furnaces and water heaters, were formed over thousands of years from decayed plants and animals that once depended on the sun for life and growth. These fossil fuels may accurately be thought of as "stored" solar energy.

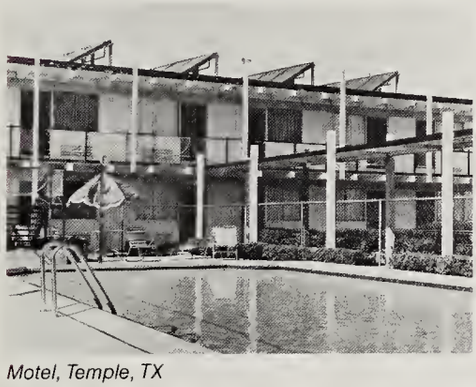
Since the onset of the energy crisis just a few years back, we have become sharply aware that the supply of fossil fuels available to us is rapidly being depleted. If we continue to deplete our fossil fuel resources at current rates, they may, in time, run out completely. Before this happens, we must know how to make *direct* use of the vast amounts of solar energy the earth receives each day. For instance, on a global scale, two weeks of solar energy is equivalent to the fossil energy stored in all the earth's known reserves of coal, oil, and natural gas. The purpose of this publication is to explain means by which solar radiation can be put to work satisfying the thermal energy requirements for space and domestic water heating.

The direct utilization of solar energy is by no means an entirely new concept. Man's tentative approaches to harnessing the sun's power can be traced over many centuries. In the past 50 years or so, applications of solar energy systems for space heating and hot water have appeared in states, such as Florida, where sunshine is abundant and fuel expensive, and in countries such as Japan and Australia. The recent energy crunch has accelerated the development of solar technology, a field in which the copper and brass industry is playing a leading role.

Solar energy systems are very practical now for many applications in the building industry, such as space heating, water heating and swimming pool water heating. Space cooling is also showing great promise of being an economically feasible option.

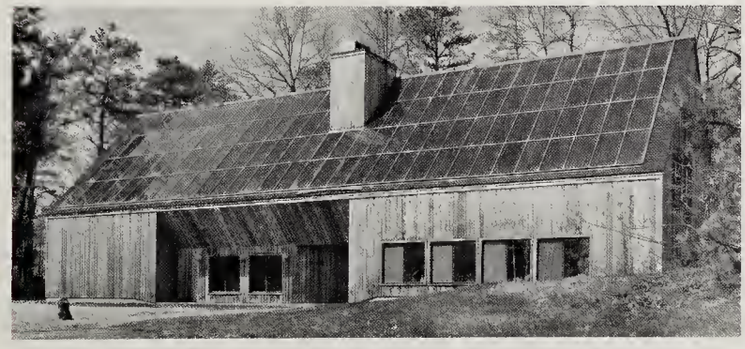
Applying solar energy to buildings involves three things. It must be collected; it must be stored; and it must be "distributed"—put to work within the structure for some purpose. Collection and storage are areas featuring some new methods, components and systems. Distribution, on the other hand, can be accomplished by the familiar means used for the traditional fossil-fuel systems.

Residence, Sugarmill Woods, FL



Motel, Temple, TX

COLLECTION/STORAGE/DISTRIBUTION

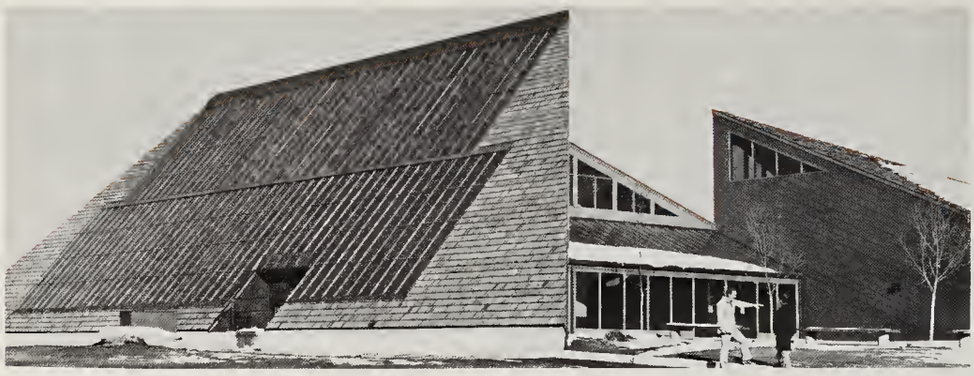


Community Center, Albany, NY

Community Center, Santa Clara, CA

SECTION 1

FUNDAMENTALS OF SOLAR ENERGY



Church, Denver, CO

Characteristics Of Solar Radiation

The sun is a star and source of most of our life and energy. Radiating in all directions, only a small percentage of its tremendous energy reaches the earth's atmosphere. The portion that actually reaches the surface of the earth is smaller still because of the reflective and filtering characteristics of the earth's protective atmosphere. Yet, despite all of these limiting factors, the amount of solar energy delivered to the earth each day is thousands of times greater than man's total daily use of energy for all purposes.

Solar energy covers a wide range of wavelengths in the light spectrum, ranging from the ultraviolet through visible light to the infrared regions. When it reaches the outer ring of the earth's atmosphere, about 30 percent of the solar radiation is immediately reflected back into space. As the remainder continues on its path through the atmosphere toward the earth, several other effects reduce its intensity. First, most of the ultraviolet and some of the infrared components are filtered out so that what is left is largely in the form of visible light.

As shown in Fig. 1, a significant portion of the incoming radiation is reflected by the clouds back into space. A smaller portion is absorbed by water particles in the atmosphere and another portion diffused by atmospheric particles, clouds and pollutants. This last portion of the sun's radiation is called *diffuse* or scattered radiation.

The remainder of the radiation which is not affected in one of these manners passes more or less directly to the earth's surface from the direction of the sun. This is called *direct* radiation. The energy available for collection is the direct radiation plus a portion of the diffuse radiation.

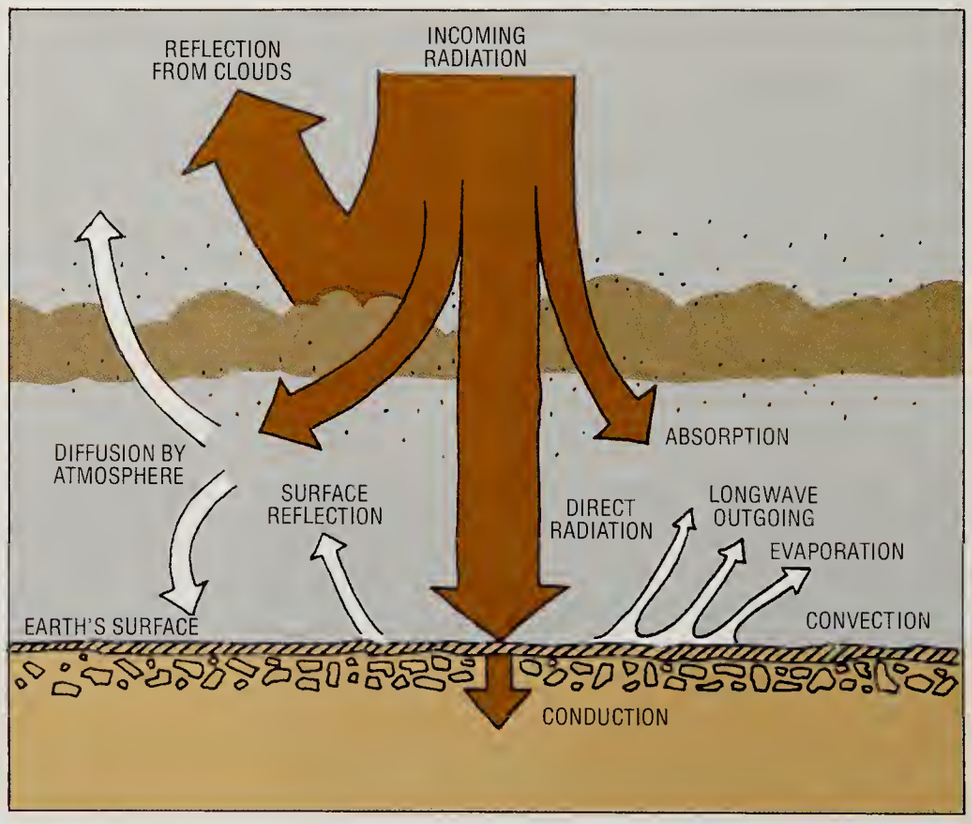


FIGURE 1/ DISTRIBUTION OF INCOMING RADIATION

Solar Geometry

The rate at which solar energy reaches the outer limits of the earth's atmosphere is the same at all times. This rate, known as the *solar constant*, is equal to 429 Btu (British thermal units) per square foot per hour falling upon a surface perpendicular to the direction of the sun's rays. Despite the fact that the sun's intensity remains the same, we experience a change of seasons as a result of the varying geometric relationships between earth and sun. These relationships are depicted in Fig. 2.

The earth revolves once each day around an axis, which passes through the North and South Poles. Because its axis is tilted with respect to the sun, the intensity of the sunshine reaching the earth's northern and southern hemispheres rises and falls as the earth makes its yearly orbit and the seasons change. The angle of this tilt, called the *declination angle*, is the primary reason for the variation in the distribution of solar energy over the earth's surface, for the varying number of hours of daylight and darkness over the year, and for the great differences in the intensity of solar energy received at any one location.

The amount of radiation which reaches the earth depends in part on the distance it travels through the atmosphere. As indicated in Fig. 3, solar energy impacts at various angles, depending upon the sun's position relative to the earth. This angle determines the length of travel. The longer its path through the atmosphere, the less direct energy will reach the earth's surface. The three classifications for lengths of travel shown are referred to as Air Mass 1, 2 and 3.

Air Mass 1 identifies the shortest path through the atmosphere and occurs when there is a 90 degree angle between the sun's radiation and the earth's surface. This position of the sun is referred to as the zenith position and it occurs at the Tropic of Cancer (23½ deg North latitude) on the summer solstice. An Air Mass of 2 exists when there is a 60 degree angle between a perpendicular to the earth's surface and the incoming angle of the solar radiation. In Air Mass 2, the sun's rays pass through twice as much atmosphere as in Air Mass 1. Similarly, in Air Mass 3, the sun's rays pass through three times as much atmosphere as in Air Mass 1.

Altitude and Azimuth

The characteristics of solar geometry have a significant effect on the physical parameters and performace of solar col-

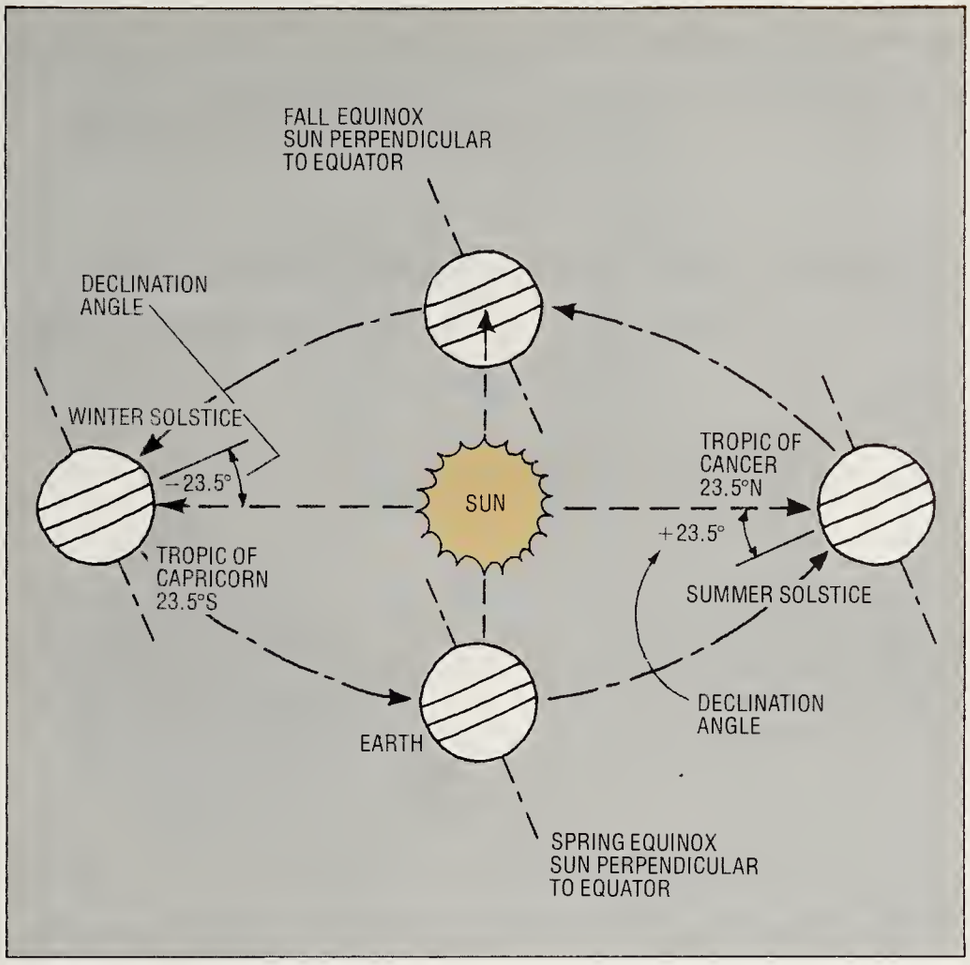


FIGURE 2/ SOLAR GEOMETRY

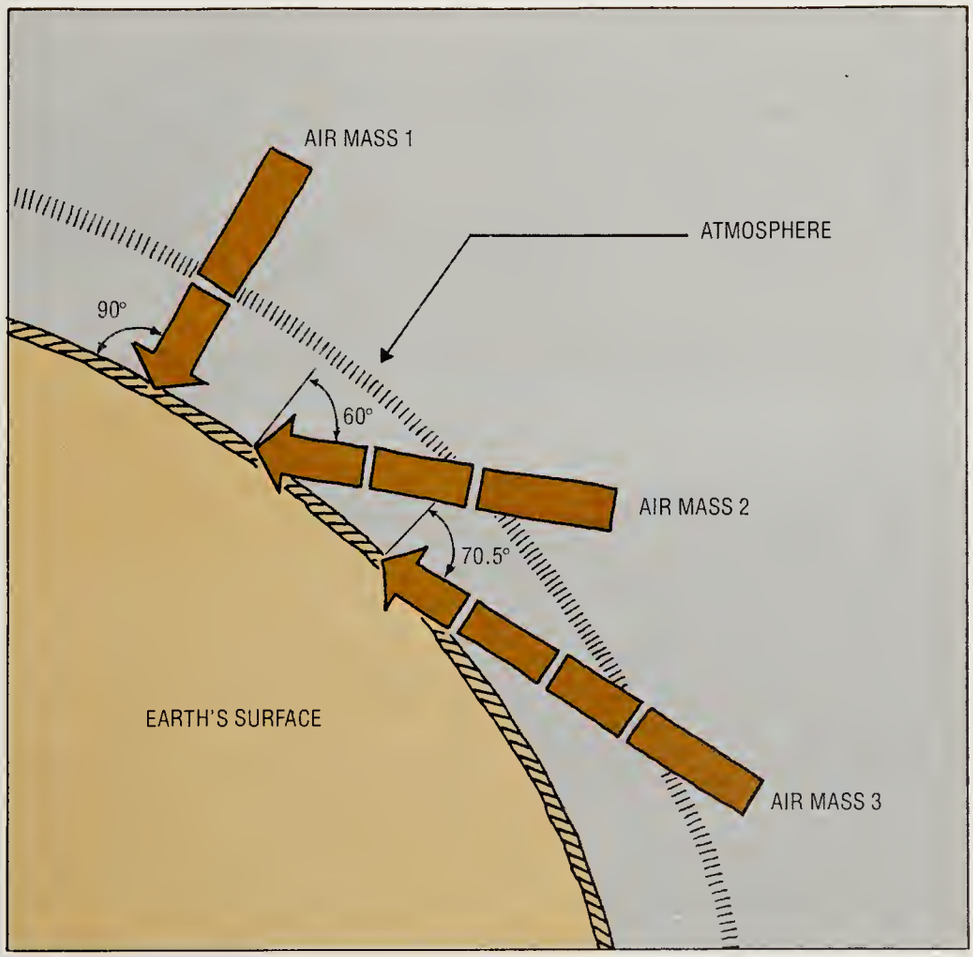


FIGURE 3/RELATIONSHIP OF INCIDENT ANGLE AND AIR MASS

lection systems. Fig. 4 illustrates typical altitude and azimuth positions of the sun at the equinox and solstice days. It can be seen from this diagram that at the summer solstice, the sun rises from a position north of due east, climbs to a high position in the sky at solar noon and sets at a position north of due west. On the equinox days, the sun rises at a position of due east, climbs to an intermediate position in the sky and sets at a position of due west. At the winter solstice, the sun rises south of due east, climbs to a low position in the southern sky, and sets south of due west. The angle of the sun's position in the sky with respect to the earth is known as the *solar altitude*. The position of the sun with respect to compass directions is referred to as the *solar azimuth*. The actual positions of solar altitude and azimuth vary each day of the year and, furthermore, are different for each position of latitude. These are two of the most significant factors in determining how a collector of solar energy should be positioned with respect to the sun.

Collector Tilt

Since the sun is low in the southern sky during winter, more solar energy will strike a flat collector if it is tilted up from the horizontal at a steep angle toward the sun. The effect of collector tilt is illustrated in Fig. 5. In summer, the flat collector will intercept more solar radiation in a horizontal position than it will tilted up steeply from the earth. It can be seen that a collector tilted up toward sun during winter will intercept more solar radiation than the same sized collector in a horizontal position.

The actual angle at which a collector should be tilted is a function of the particular characteristics of the intended application. If the intention is to collect the most solar energy in the winter period, the collector tilt should be steep. Conversely, if the intention is to collect the most heat during the summer period, collector tilt should be relatively flat.

There are convenient rules-of-thumb for determining the most appropriate collector tilt. These are as follows:

A. To collect the most radiation in the winter period, tilt the collector at an angle equal to the latitude plus 15 degrees.

B. To collect the most solar radiation during the summer period, tilt the collector at an angle equal to the latitude minus 15 degrees.

C. To collect the most radiation averaged over the year, tilt the collector at an angle approximately equal to the latitude.

These rules should be taken as guidelines only and adjusted for the specific characteristics of an application.

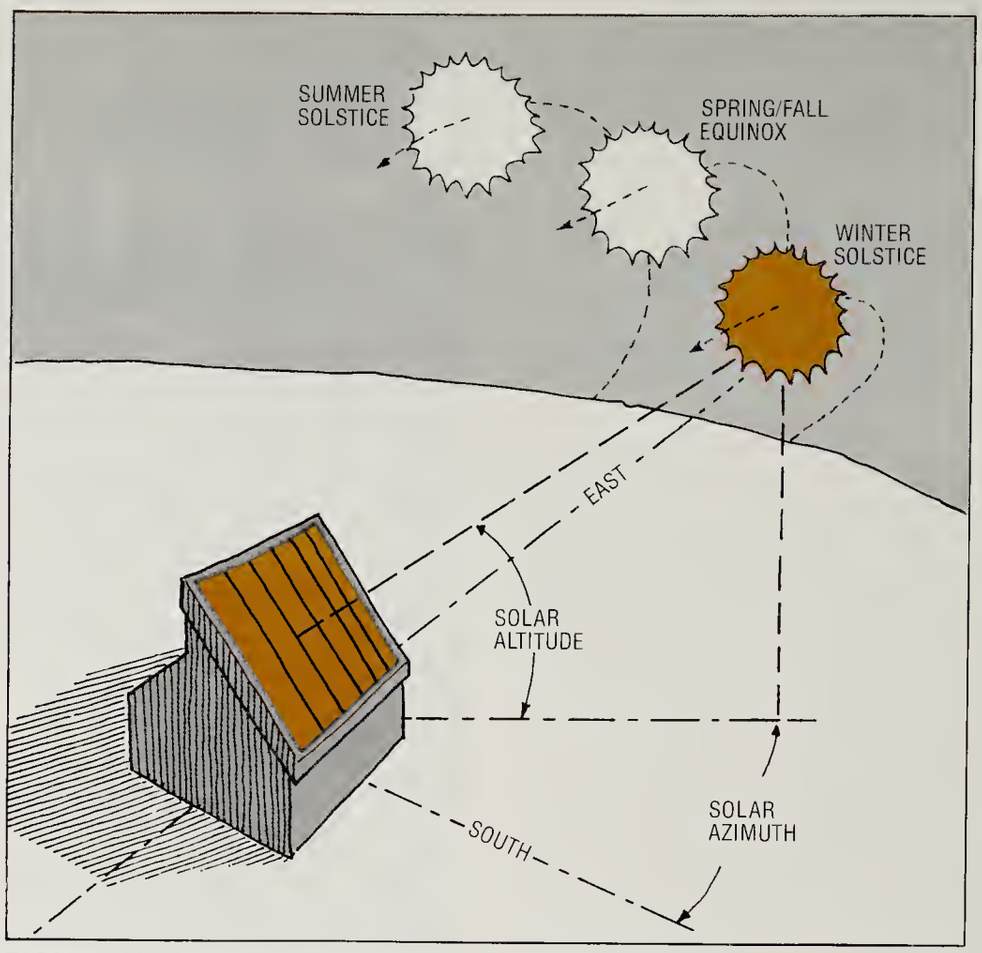


FIGURE 4/ ALTITUDE AND AZIMUTH

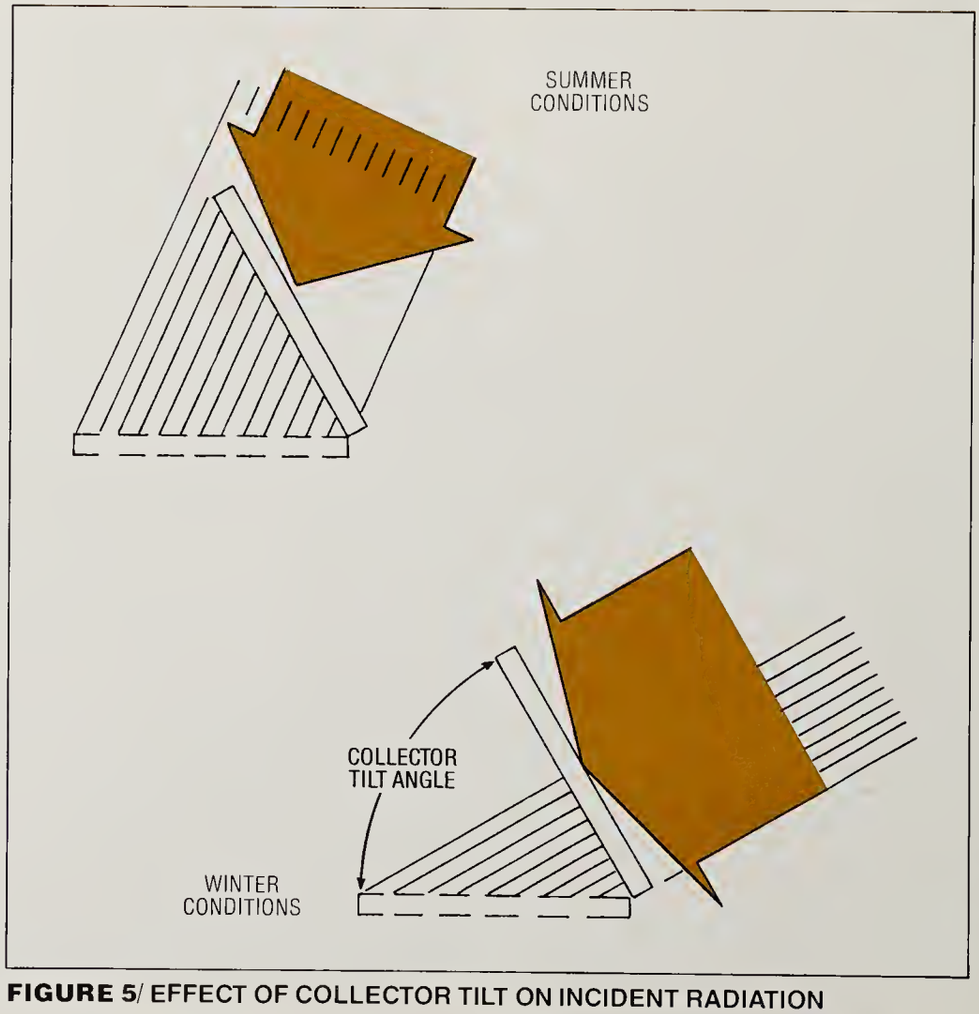


FIGURE 5/ EFFECT OF COLLECTOR TILT ON INCIDENT RADIATION

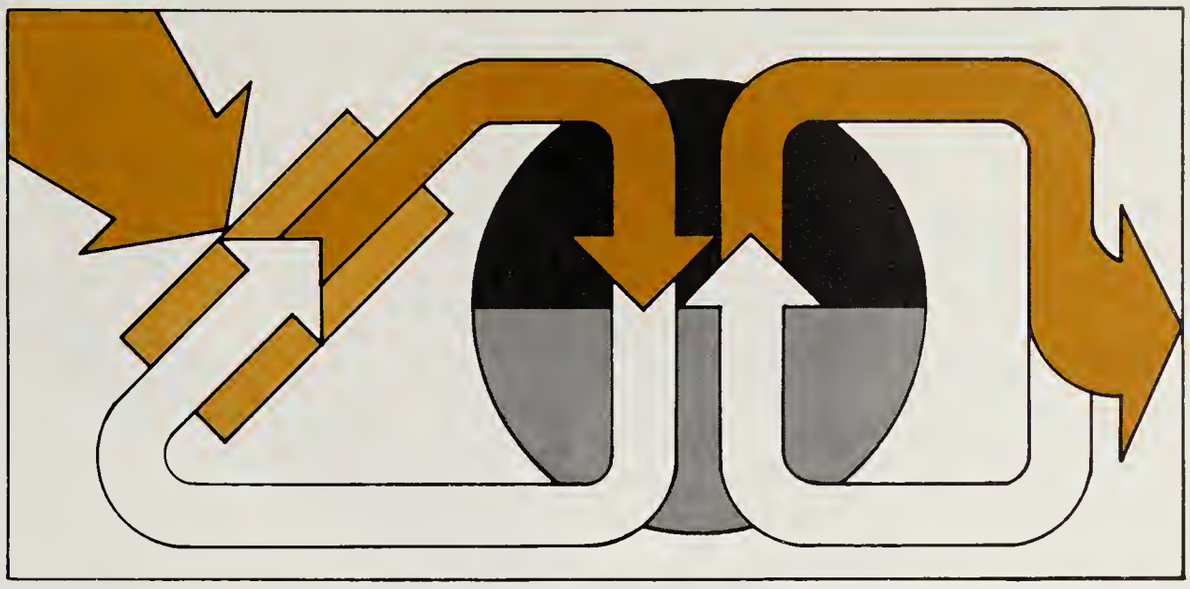


FIGURE 6/ COLLECTION, STORAGE AND DISTRIBUTION ARE THE THREE BASIC COMPONENTS OF ALL SOLAR ENERGY SYSTEMS.

SECTION 2

COLLECTION

Solar radiation out in space has a characteristic pattern of wavelengths and intensity. By the time this radiation reaches the earth, most of the ultraviolet component has been filtered out. What remains is mostly in the visible region of the spectrum, with a smaller portion covering the short infrared region, as shown in the left portion of Figure 7. This incoming radiation is converted to heat when absorbed by a surface, such as that of the blackened copper *absorber plate* in a solar collector.

Some of the absorbed energy will be lost from this surface, by either conduction, convection, or re-radiation. Conducted losses come from direct contact with a colder material, while convection losses arise from heat being carried away by air currents. Surfaces also re-radiate absorbed energy, but its wavelength will have changed to "long infrared", also shown in Figure 7. This outgoing energy is a significant factor in the design and performance of the collectors in the solar heating system.

There are many possibilities for the collection of heat from solar energy. Direct gain through window areas is one, but this often provides too much heat when and where it is not needed and the resulting energy is difficult to control. Aiming to store this energy for future use, most solar energy collection systems utilize a heat-transfer fluid—either a liquid or air—to move the collected thermal energy from the collectors to a heat storage material. The collectors are typically one of two basic types: concentrating collectors or flat-plate collectors. Concentrating collectors utilize lenses or reflective surfaces to focus the sun's rays onto a relatively small absorbing area, and are able to build up higher temperatures than flat-plate collectors. Concentrating collectors

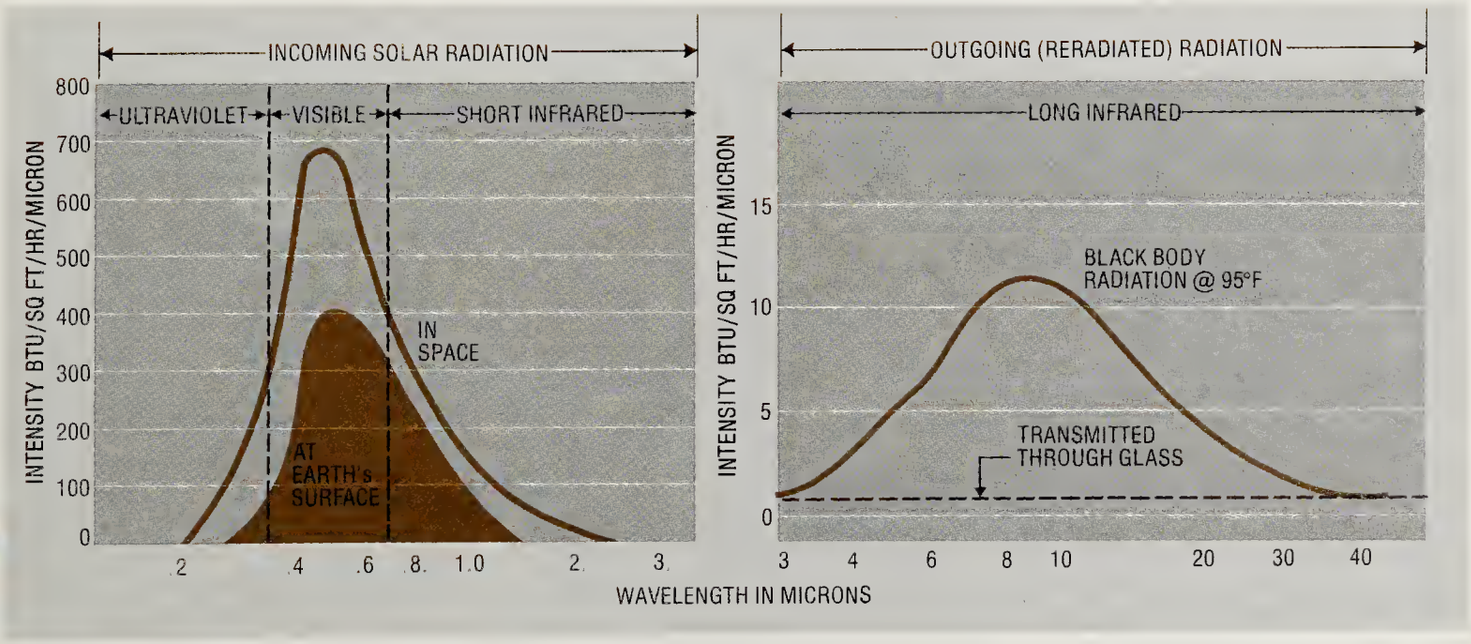


FIGURE 7/ SPECTRAL DISTRIBUTION

are generally unable to effectively focus the diffuse component of solar radiation, and thus their performance is based largely upon available levels of direct insolation.

Flat Plate Collectors

Flat plate collectors take advantage of both the diffuse and direct radiation falling on the absorber plate. In order to collect as much energy as possible, the collectors are often covered with a glazing material, such as glass or certain plastics, which are highly transparent to the incoming solar radiation. These covers serve as insulation over the absorber plate, as they keep convective heat losses down. In addition, glass is virtually opaque to the outgoing long-wave infrared radiation, and thus traps this radiation inside the collector, a phenomenon known as the "greenhouse effect".

Figure 8 illustrates how this phenomenon affects the performance of three different collector types. In the first type, Flat Black Plate Without Glazing, much of the radiation absorbed by the absorber plate is lost from the top surface of the plate, with some lost through the back insulation. Some useful heat is retained without a glazing cover, but only if the temperature of the absorber plate is close to the temperature of the surrounding air.

In the second type, Flat Black Plate With Glazing Cover, the radiation absorbed by the black plate is re-emitted as it was in the previous type. But the glass cover blocks the loss of the re-emitted radiation to the outside. There is some heat loss through conduction and convection, but more heat is retained with a glazing cover. This is especially true as the temperature difference between plate and outside air becomes greater. It may be desirable to utilize more than one layer of glazing, depending upon the magnitude of the temperature difference.

The third portion of Fig. 8 illustrates a collector with a Selective Surface and Glazing Cover. A selective surface is a very thin layer of special material applied to the top of the absorber plate. The layer's thickness is approximately equal to the wavelength of the incoming solar radiation. The selective surface reradiates a much smaller portion of the absorbed energy, which makes the collector operate more efficiently. There is still some heat loss through conduction and convection to the outside air, but more heat is retained with a selective surface than with an ordinary flat black surface. A selective surface may be used with single or multiple glazing. Selective surfaces are especially useful in collectors that operate at high temperatures. They in-

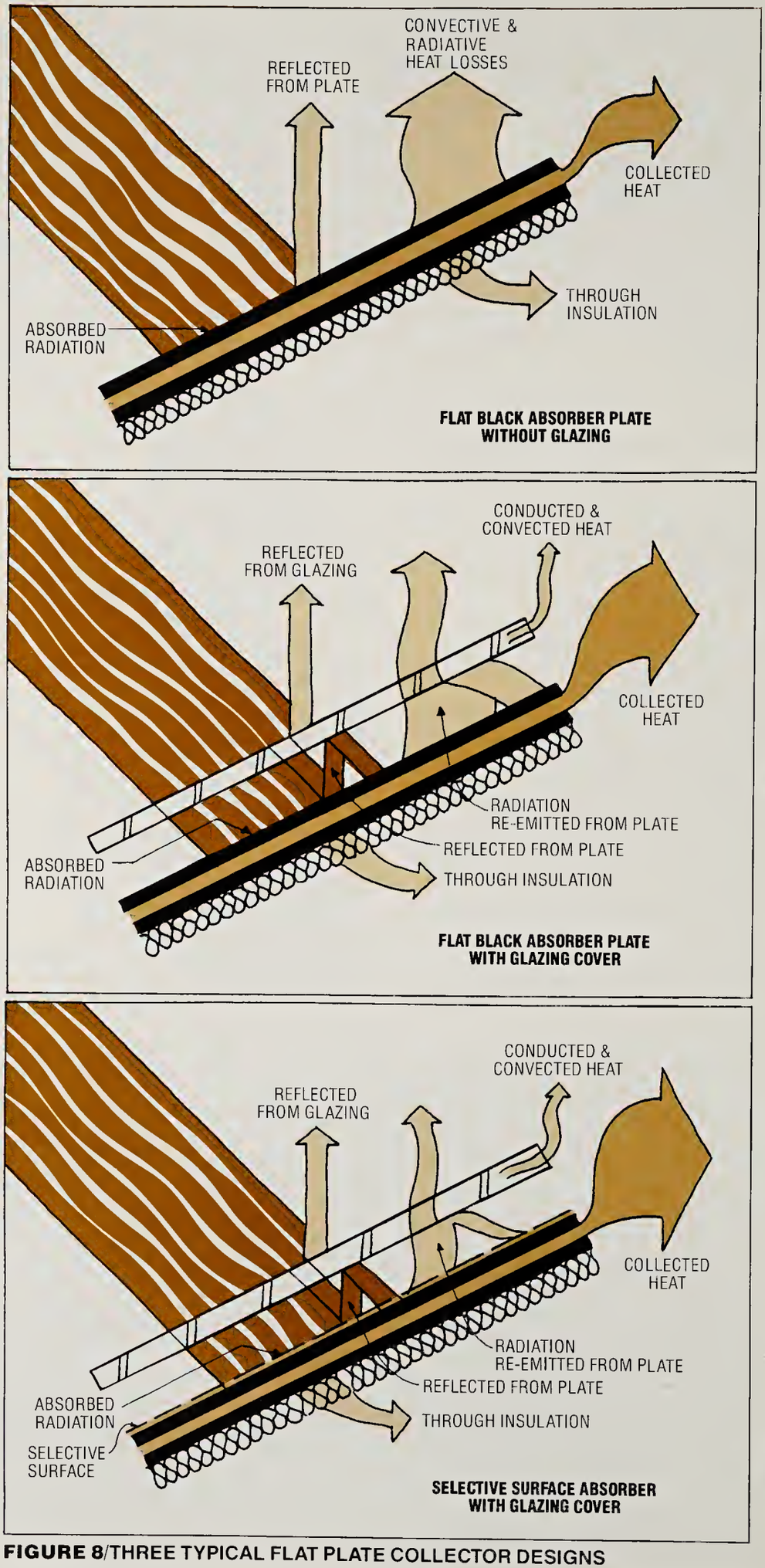


FIGURE 8/THREE TYPICAL FLAT PLATE COLLECTOR DESIGNS

crease collection efficiency, but at the premium of higher cost than non-selective flat black surfaces.

Collector Construction

Flat plate collectors utilize liquid as the heat transfer medium. Typically they have blackened copper absorber plates with an integral or attached array of copper tubes. This absorber plate may be packaged into a modular collector panel, which is complete with glazing covers, insulation, and enclosure box, or the absorber plate may be incorporated as an integral part of a roof or other structure.

Figure 9 illustrates the major components of a typical modular liquid flat plate solar collector panel. There are one or two layers of glazing material held by a frame over a blackened copper absorbing plate. The plate has an integral or attached array of tubes for circulation of a liquid. The liquid inlet connection shown at the bottom of the collector is diagonally opposite the liquid outlet connection at the top. Usually this configuration is used so the flow length is the same through every passage. The aim is to achieve a balanced flow of liquid through the collector and, thus, maintain a relatively uniform temperature pattern over the plate.

Site-fabricated collectors may have the absorber plate laid over or between structural members. Insulation is placed behind, and glazing covers, if appropriate, are installed over the absorber plate. Care must be taken to insure that the cover and insulating materials are compatible with the high temperatures reached by the absorber plate. Properties of appropriate materials are covered in Section 6–Design Recommendations.

The solar collector must be protected from freezing in the winter and from very high temperatures which can occur when liquid is not flowing through the collector. Also, when cold water is put into a hot collector, a thermal shock can occur, damaging the collector. Methods of providing protection against thermal shock and freezing are contained in Section 6–Design Recommendations. Methods of freeze protection are also covered in Section 4–Distribution: Domestic Water Heating.

Beneath the absorber plate is an insulating material that retards loss of the absorbed heat through the back of the collector panel. Heat losses from the sides of the collector panel are minimized by maintaining a space or "thermal break" between the metal absorber plate and the collector framing.

It is helpful to maintain a moisture-free condition in the collector to retard the loss of heat which tends to be greater in moist air than in dry air. A second reason is to prevent condensation of water on the glazing covers which would reflect incoming solar radiation away from the collector.

One method for keeping air within the collector dry is the incorporation of spacers made of a desiccant (moisture-absorbing) material. These spacers are inserted between cover and absorber plate and, also, between layers of multiple-glazing covers.

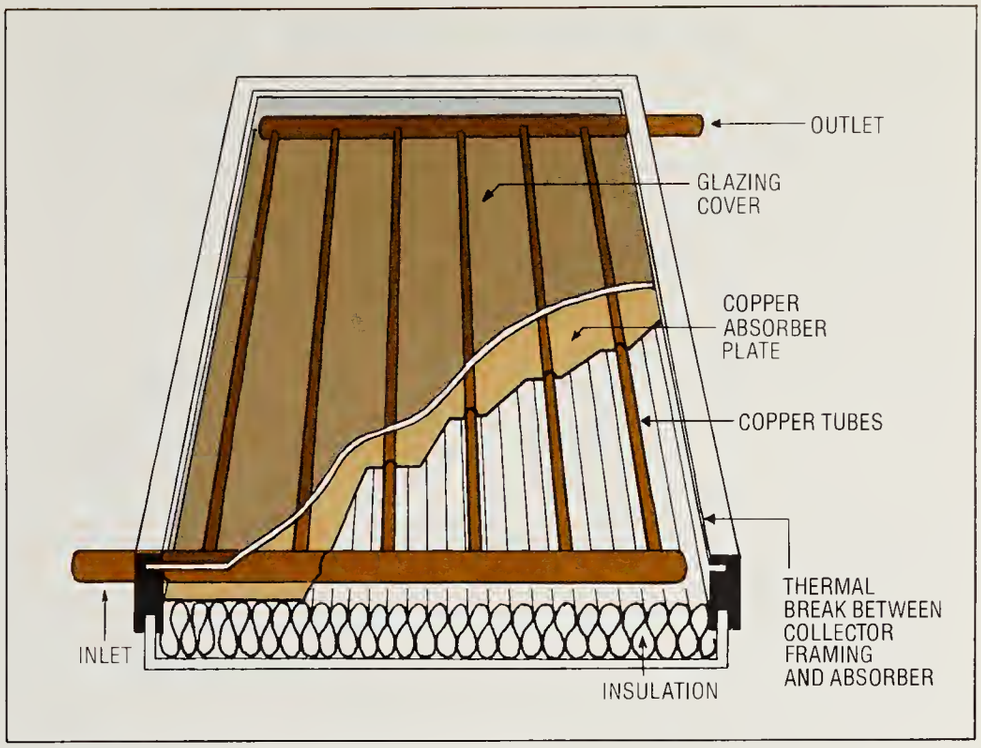


FIGURE 9/ TYPICAL FLAT PLATE COLLECTOR

Collector Efficiency

A collector's usefulness depends mainly on how much of the solar energy it can make available for heating. This is its efficiency. The operating efficiencies of several different types of collectors are compared schematically in Fig. 10. The significant improvement achieved by adding glazing covers is immediately apparent. Fig. 10 reveals several other general conclusions about the

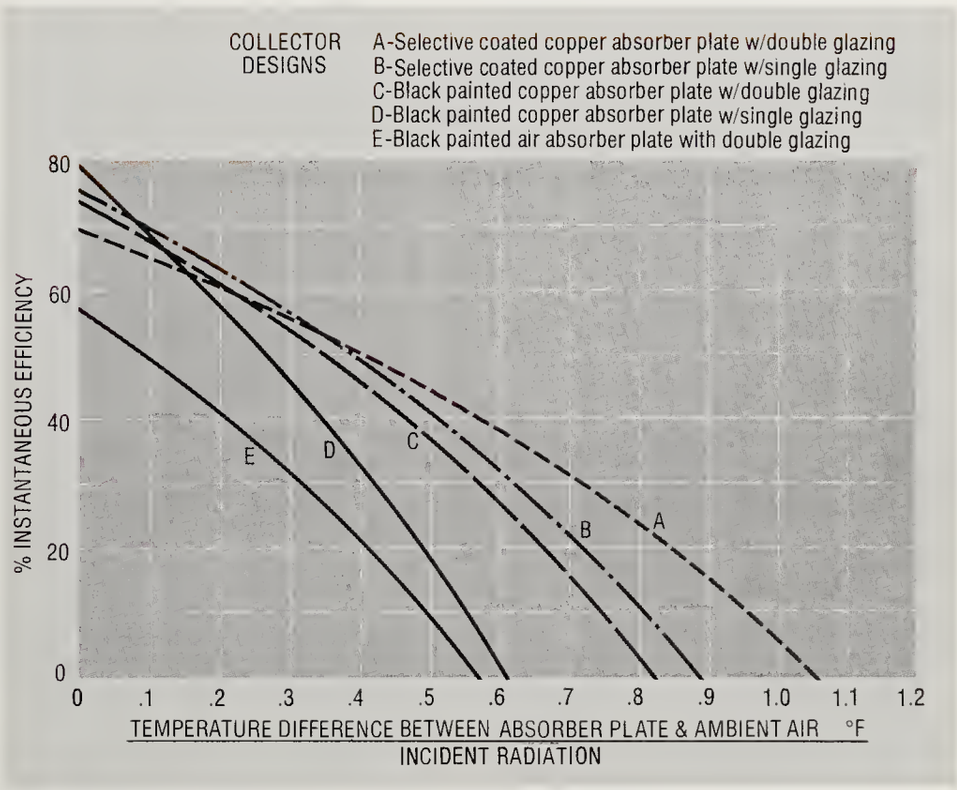


FIGURE 10/ PERFORMANCE EFFICIENCY OF TYPICAL COLLECTORS

efficiency of collectors:

1. All collectors operate with highest efficiency when the difference in temperature between the absorber plate and ambient air is lowest.

2. For the same temperature difference, efficiency will be higher if the incident solar radiation is higher. Thus, at the same temperature difference, higher efficiencies can be expected in summer when more solar energy is available than in winter when less solar energy is available at the collector surface.

3. The highest possible efficiencies are achieved when there is no temperature difference between the absorber plate and the surrounding air. But even under this condition, 100 percent efficiency is not achievable. This is because there are always losses caused by incomplete transmission through the glazing covers, reflectance from the blackened absorber plate, and incomplete transfer of heat absorbed by the absorber plate into the heat transfer liquid or air.

4. The choice of collectors should be related to the operating temperature difference, the amount of solar radiation available, and the cost of adding options such as selective black surfaces or additional glazing covers. It can be seen from Fig. 10, for example, that in the range of 0 to 20°F temperature difference, such as might exist in a swimming pool heater application, a collector with no cover plates is an appropriate choice. When high temperature differences are anticipated, such as in solar cooling operations, a selective surface may be needed to obtain these temperatures.

5. Collector efficiency is increased by minimizing the temperature rise from collector inlet to outlet. A common range is 7 to 10°F; this can be accomplished by circulating water at the rate of 1 to 3 gallons per square foot of collector per hour.

It is important to realize that Fig. 10 represents the *instantaneous* efficiency of solar collector operation. This is the efficiency at a particular time, usually stated as an hourly efficiency. The lines plotted on this graph are based upon a specific intensity of solar energy available at the collector plate. During the day, the amount of solar radiation available to the absorber plate varies continually.

Fig. 11 illustrates the relationship between time of day and intensity of solar radiation. The horizontal line, marked "critical or threshold intensity", represents the point at which the heat losses from the absorber plate (determined by the temperature difference between the plate and the surrounding air, and collector design) are equal to the heat gain experienced by the plate.

This line moves up if the temperature difference becomes greater, down if the temperature difference becomes less. When the intensity of radiation reaches this threshold point, the collector begins operation. No heat would be produced if the system were operated before this threshold intensity was reached. In fact, if the collector system were operated below threshold intensity, heat would be lost from the previous day's collection.

It can be seen that there are portions of the daily solar radiation that are too low in intensity to justify operation of the collector. These are signified by the shaded triangular areas below the line of critical intensity. After the critical intensity has been reached and the collector has begun operation, the instantaneous efficiency of the collector varies through the period of collector operation. At the beginning and end of the period of

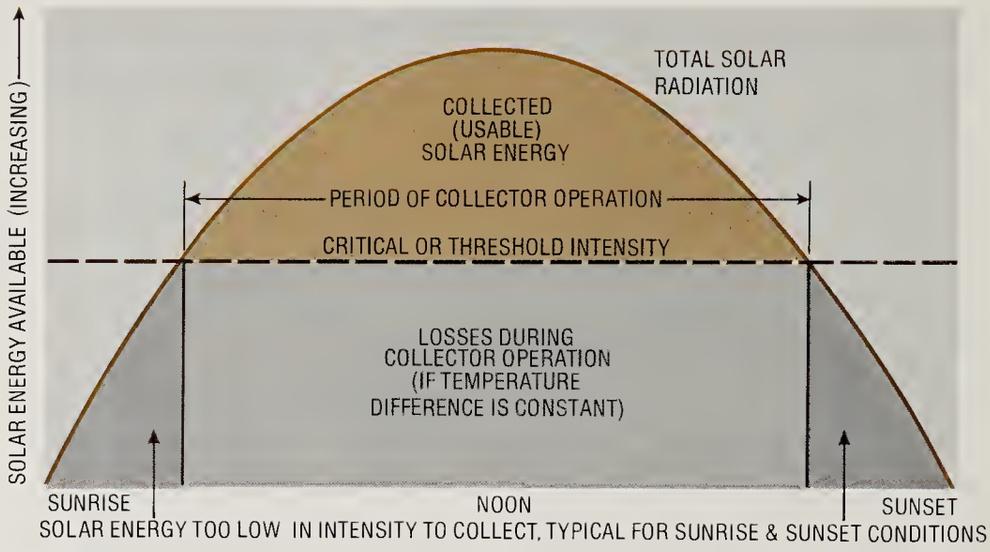
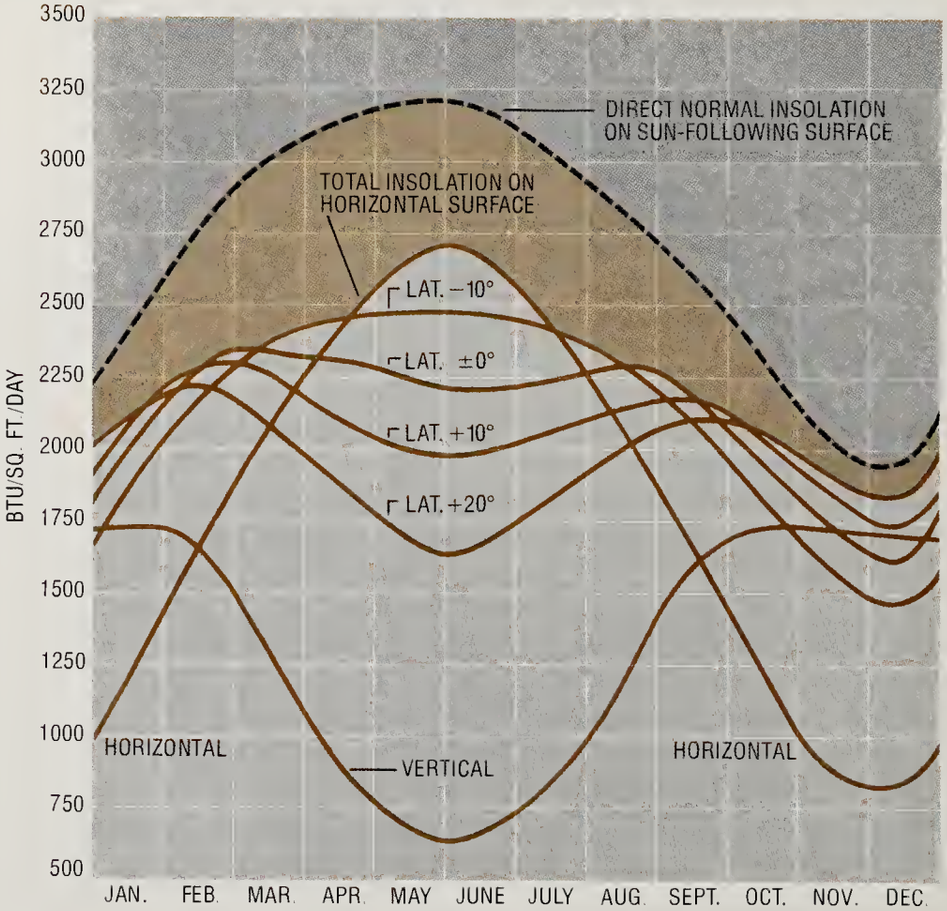

SOLAR ENERGY AVAILABLE (INCREASING)
TOTAL SOLAR RADIATION
COLLECTED (USABLE) SOLAR ENERGY
PERIOD OF COLLECTOR OPERATION
CRITICAL OR THRESHOLD INTENSITY
LOSSES DURING COLLECTOR OPERATION (IF TEMPERATURE DIFFERENCE IS CONSTANT)
SUNRISE
NOON
SUNSET
SOLAR ENERGY TOO LOW IN INTENSITY TO COLLECT, TYPICAL FOR SUNRISE & SUNSET CONDITIONS

FIGURE 11/ COLLECTION OF SOLAR RADIATION THROUGHOUT THE DAY



Solar radiation on horizontal and south facing surfaces at various collector tilts, 40° north latitude, 21st day of each month, clear sky conditions.
SOURCE: 1974 ASHRAE Applications Handbook and Product Directory.

FIGURE 12/ COMPARISON OF COLLECTOR TILTS

collector operation, for example, very little solar energy is collected in comparison with the collector's operational losses. The instantaneous efficiency of operation will be quite high at the midpoint of the period of collector operation.

There is an important difference between instantaneous collector efficiency and day-long collector efficiency. The day-long collector efficiency is the amount of solar energy collected as a percentage of the total available for the entire day, including portions too low in intensity to operate the collector. Some collector manufacturers judge their collector performance by instantaneous efficiency. While this indicates the collector's capabilities, the figures cannot be applied to the entire day's solar radiation.

Collector Tilt And Orientation

The amount of energy falling on the collector surface during the year at any position of latitude, depends upon the tilt and orientation of the collector. Fig. 12 shows how collector tilt affects incident radiation at 40 deg north latitude on a cloudless day. The radiation incident on a horizontal surface experiences a sharp peak during the month of June when the sun is high in the sky. It falls off very sharply toward the winter months when the sun is much lower.

Tilting the collector to 30 deg (equivalent to the position of latitude minus 10 deg) flattens the curve somewhat. Maximum production still occurs during summer, but there is a significant improvement in production during winter. Further increases in tilt to 40 deg (equal to the latitude of the installation), to 50 deg (latitude plus 10 deg), and to 60 deg (latitude plus 20 deg) cause progressive shifts of the curve so that the maximum production occurs more toward the winter heating season. For this latitude, a collector tilted vertically (90 deg) experiences its greatest amount of incident energy during winter, but the collected energy drops off sharply during summer.

The dashed line on the top of the graph shows the amount of solar energy incident on a surface which "tracked" or followed the sun, always adjusting its tilt and orientation so that solar energy was received at right angles. Although there is somewhat more energy incident on such a surface, the economics of building a mechanism to allow the collector to follow the sun may not be justifiable.

Orientation refers to the compass direction in which the collector faces. It also plays a significant role in determining the amount of incident energy, as shown in Fig. 13. Orientation of collectors used for space heating systems is especially important. It can be seen that in winter, when the sun rises south of due east and sets south of due west, an orientation of southeast or southwest (45 deg from due south) receives only 70 to 80 percent of the radiation received by a south-facing surface at the same tilt.

The actual percentage figure depends upon the latitude, with the more northerly latitudes (which experience shorter days) suffering the greatest reduction in incident radiation for variations from a south orientation. In spring and fall, orientation becomes less critical. In summer, orientation is least critical, with south facing surfaces actually receiving slightly less radiation during June than surfaces facing south-southeast or south-southwest.

Since collector heat production capacity is affected by the temperature of the surrounding air, local conditions at the point of collection are also important. In most areas, maximum air temperature is reached in the early afternoon, usually around 2 to 3 p.m. Also, many locations experience morning haze which clears by early afternoon. Where such conditions prevail, peak collection may be experienced by a collector which faces 10-15 deg west of south, instead of the theoretical value of due south.

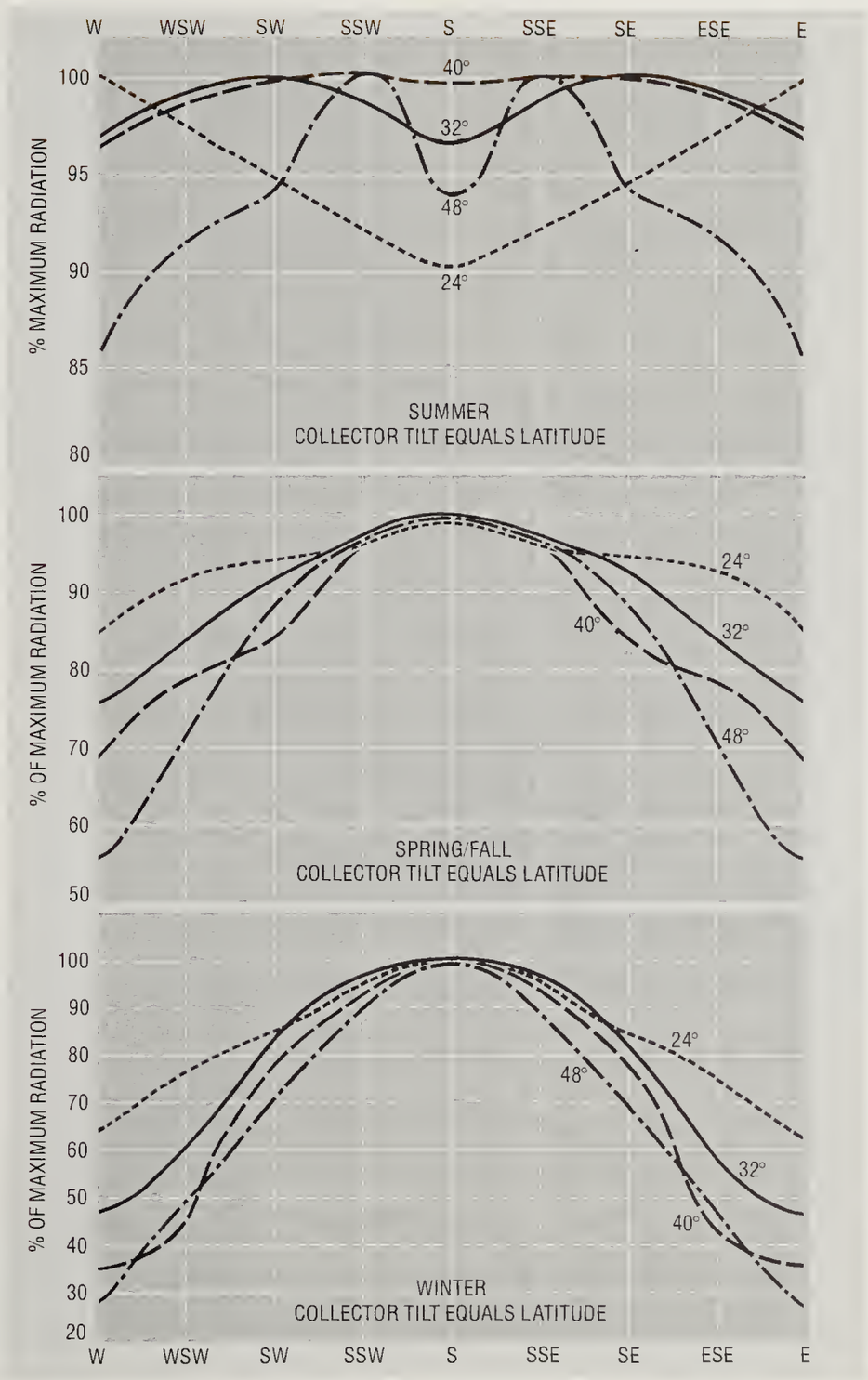


FIGURE 13/ EFFECTS OF COLLECTOR ORIENTATIONS

Approaches to Heat Storage

Allowing for the intermittent quality of sunshine, any practical system must include a capability for storing the collected solar energy until it is needed. However, in most applications it is not economically feasible to install storage capacity large enough to guarantee a supply of solar-heated water at all times. A more practical approach is to rely on solar energy for a portion of a building's heating needs and to supplement it with a second heat source, using electricity or one of the fossil fuels. The solar system can be sized to meet a portion of the normal space and water heating requirements, while the supplementary heat source stands by in readiness for times when there are long periods without sunshine or when demand for heat is unusually heavy.

There are two basic types of storage: sensible heat storage and latent heat storage. Sensible heat storage is based on the principle that a definite amount of energy is required to raise the temperature of a unit volume of a given substance 1°F. "*Unit heat capacity*" is equal to the specific heat of the material times its density. Water, for example, has a specific heat of 1.0 and a density of 62.5 lb./cu ft. Therefore, 1 cu ft of water will rise in temperature 1°F when 62.5 Btu is applied.

Table 1 indicates the sensible heat storage capacity of various types of solid and liquid materials. Liquid sensible heat storage materials are most commonly used with liquid flat-plate collectors. Similarly, solid sensible heat storage materials are most commonly used with air flat-plate collectors. A significantly greater volume of solid materials is required to attain the same amount of heat storage as water because the specific heat is much lower for solid materials than it is

	Specific Heat BTU/Lb. °F.	Density Lb./Ft.³	Unit Heat Capacity BTU/Ft.³/°F. No Voids	Unit Heat Capacity BTU/Ft.³/°F. 30% Voids
Water	1.0	62.5	62.5	(62.5)
Water (30%)—Ethylene Glycol (70%) Mixture (230°F.)	.8	64.1	51	36
Scrap Iron	.112	489	55	38
Magnetite	.165	320	53	37
Scrap Aluminum	.215	168	36	25
Concrete	.27	140	38	26
Rock (Basalt)	.20	180	36	25
Brick	.2	140	28	20
Rock Salt (NaCl) (30-70% by weight at 230°F.)	.219	136	30	21

TABLE 1/SENSIBLE HEAT STORAGE MATERIALS

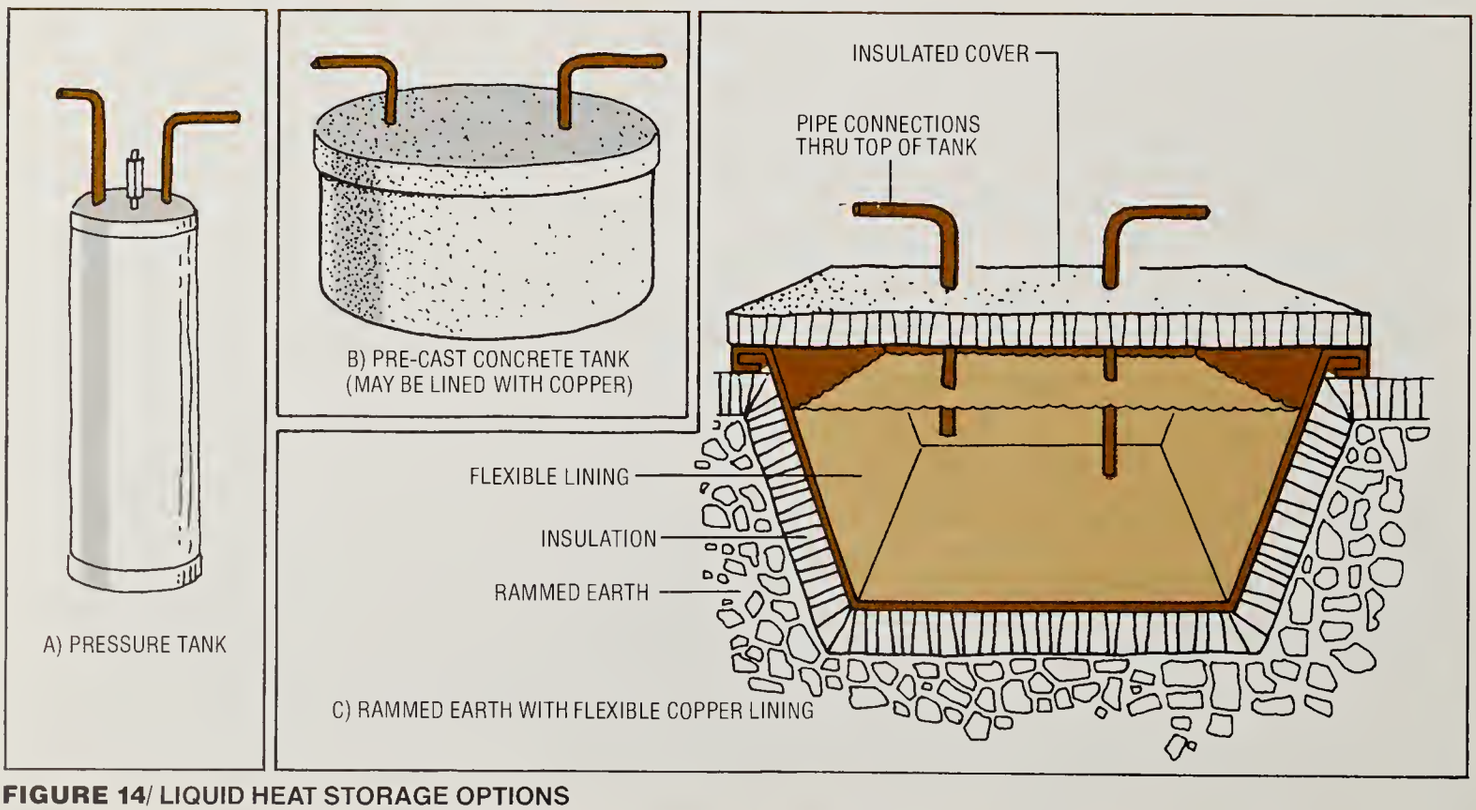


FIGURE 14/ LIQUID HEAT STORAGE OPTIONS

for water. Solid materials must also make an additional allowance for the circulation of air around the materials to cause the heat transfer to take place. A common solid-to-void ratio is 70 percent solid to 30 percent void for solid sensible heat storage materials. Thus, solid heat storage volumes will be two to three times liquid heat storage volumes for the same storage capacity. Also, greater fan motor horsepower is often required to circulate air through the storage medium, the supply ducts and the collector.

Latent heat storage makes use of the principle that it takes considerable energy to change the physical state of a substance (such as from a solid to a liquid). The material gains sensible heat until it reaches the melting point. It then gains an amount of latent heat equivalent to its heat of fusion which causes a change of state. The temperature (dry bulb) of the substance remains constant throughout the change of state.

When water changes from a solid (ice) to a liquid, about 143.5 Btu are required per pound to make the change of state. After the solid has turned to a liquid, only 1 Btu per pound is required to raise the temperature of water 1°F. A total of 8970 Btu of heat are required to change a cubic foot of ice into water. Once the change of state has been accomplished, however, only 62.5 Btu are required to raise one cubic foot of water 1°F.

The volume of the storage required for solar energy systems would be much smaller if the principles of latent heat storage could be used effectively. The choice of a storage material which has a melting point near the temperature at which the heat is to be used is important. Materials called "eutectic salts" change state at temperatures in the range of 90 to 120°F. Latent heat storage utilizing eutectic salts is not recommended unless a dependable means of assuring the stability of eutectic materials through many changes of state can be provided.

Water Storage Systems

Water is the most commonly used liquid heat storage material because of its availability and low volume requirement. There are many options for the containment of the water in a liquid sensible heat storage system. Some containers are illustrated in Fig. 14.

Domestic water heating systems require the use of tanks which are pressure tested. These tanks are frequently lined with a copper alloy material to provide protection from corrosion and to increase durability. Many manufacturers produce special domestic hot water tanks which are designed for solar systems. Some have an internal heat exchanger to permit a nontoxic antifreeze solution to be used in the collector loop. Most have four pipe connections–two for collector supply and return tubing, one for fresh water supply and one for domestic hot water supply. With potable water in the collector loop, a standard water heater can be adapted for use in a solar system by connecting the cold water and the collector supply lines into the drain outlet of the existing hot water tank.

Space heating systems are normally not pressurized. When operating at atmospheric pressure, a variety of options exist for storing the water. Commercially available liquid storage containers are frequently used. The container also may be made of pre-cast concrete, concrete block, pressure-preserved wood, or rammed earth. It is advisable to use a flexible liner in the site-built storage tank to prevent leaks. Sheet copper is an appropriate material for this application.

It is important to minimize the "thermal inertia" of the storage system. If there is a large storage volume to heat up, it may take considerable time before the storage temperature is useful for the system application. In large systems, such as those in commercial projects, it is appropriate to use more than one storage tank to provide sufficient storage capacity without imposing a large thermal inertia on the system. Multiple tank storage systems require sophisticated controls to allow the automatic determination of the fluid pumping sequence from among the various tanks to the collector and the building load.

The most appropriate storage volume for economics and system performance in space heating systems is approximately one to two day's building heat requirements under average winter conditions. Fig. 15 shows the water storage volume requirements in gal/sq ft of collector area to achieve the best system performance. The line relating storage volume and collector area has a sharp curve at about 1.75 gal of water per sq ft of collector. If much less volume is provided, the load fraction supplied by solar will drop. If much more volume is provided, little benefit will be obtained. Therefore, the most appropriate storage size is 1½ to 2 gal of water per sq ft of collector.

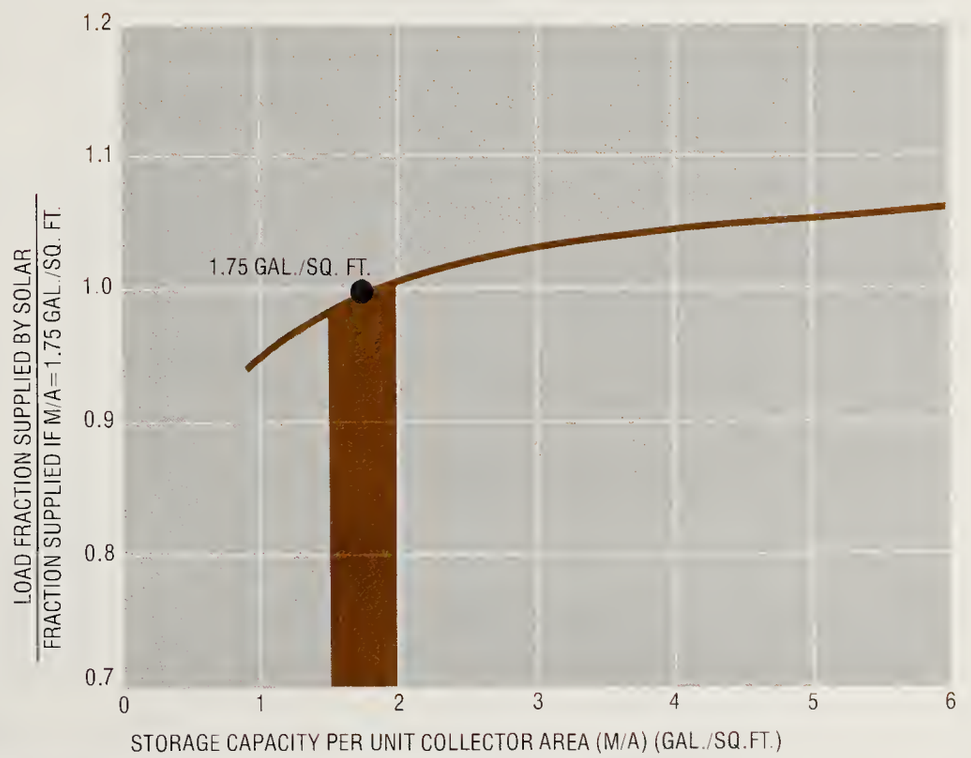


FIGURE 15/ OPTIMUM WATER STORAGE VOLUME

DISTRIBUTION: DOMESTIC WATER HEATING

Residence, Mamaroneck, NY

General Requirements

Domestic water heating is an area of high potential for the application of solar energy in buildings. There are many approaches to the design of successful solar water heating systems. The principal differences among them relate to the ways by which the heat transfer fluid is circulated between collector and storage tank, the type of freeze protection provided and the means for introducing supplementary heat.

The approach chosen for a particular application will depend on variables such as climate, heat requirements, and available storage capacity. Despite the existence of such variables, all applications have several things in common:

1. Tapwater temperature requirements are fairly consistent and are compatible with the fluid temperatures obtainable from solar collectors.
2. The collectors, pipe connections, and storage tanks in solar energy systems that operate under pressure from city water mains or on-site pumps, must be capable of withstanding these pressures. These are similar to those pressures encountered in conventional water heating systems.
3. For most efficient operation, the water brought to the collector for heating should be the coldest available. Thus, the collector supply line should draw from the bottom of the storage tank where the coldest water is located. Return from the collector should enter near the top of the tank.
4. A three-way modulating valve should be used at the point where the storage tank feeds into the building's hot water supply pipes. The purpose of this valve is to automatically maintain downstream water temperature in the 135-140°F range by blending hot and cold water. During the summer months, water stored in the tank could reach very high temperatures. The modulating valve effectively prevents scalding water from reaching the taps.

Collection: System Types and Configurations

Thermo-syphon System. In this most basic solar water heating system, the circulation of the water between tank and collector is maintained by the natural convection currents that are set up when water is heated. As shown in Fig. 16, there is no heat exchanger in the tank and the same water that circulates through the collector will later appear at the hot water tap. When the water in the solar collector becomes hotter than the

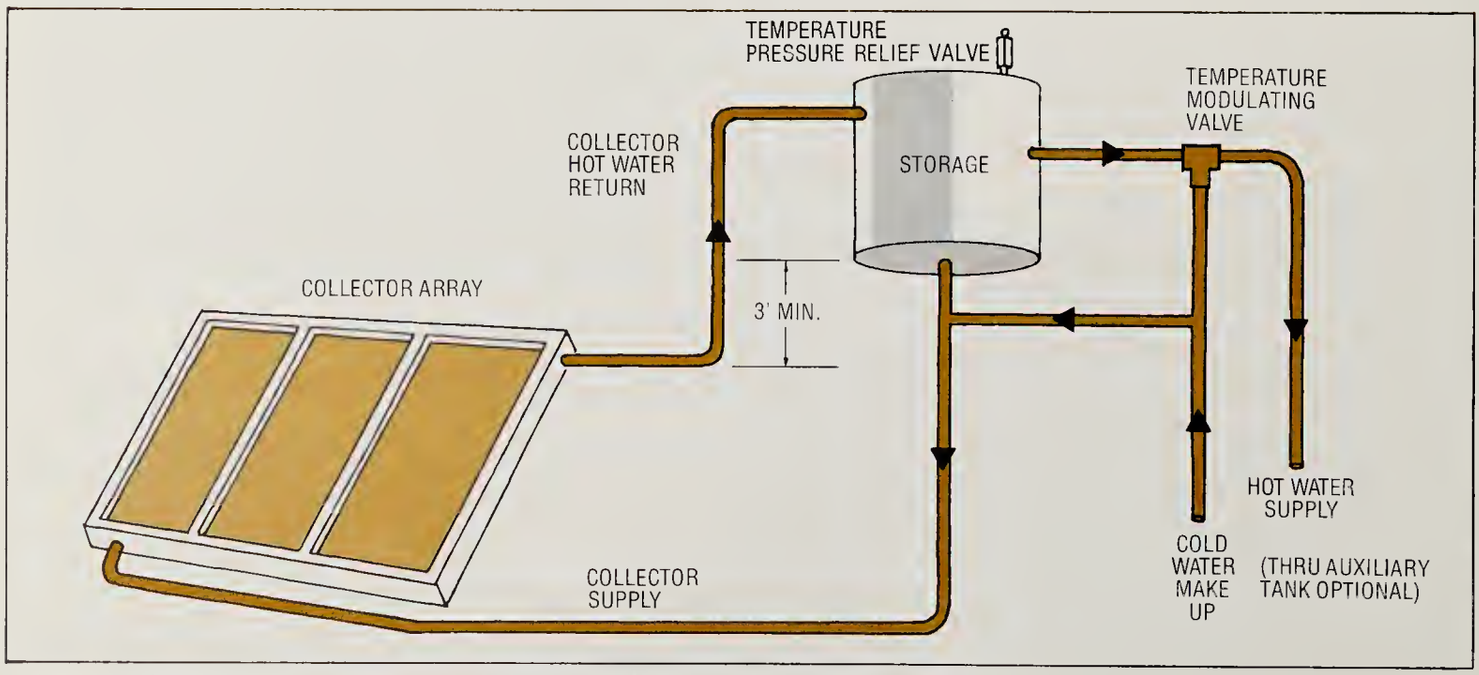


FIGURE 16/ PRESSURIZED THERMO-SYPHON DOMESTIC WATER HEATING SYSTEM

water in the storage tank, it rises to the tank. At the same time the colder tank water drops into the collector supply line. Assuming that no water is being run off at the tap, circulation will continue until tank and collector temperatures are equalized.

Lacking both circulating pump and heat exchanger, this approach offers appealing simplicity. But it has some limitations, one of which is that the rate of flow cannot be controlled. Also, because it is difficult to provide freeze protection without draining the collectors, this system is most appropriate for regions that do not reach freezing temperatures.

Pumped Circulation with Heat Exchanger. In the system depicted in Fig. 17, collector water is pumped through a closed pipe loop incorporating a heat exchanger coil which is immersed in the storage tank. Because collector water and domestic water do not intermingle, an antifreeze solution can be added to the collector water for low-temperature protection. Single-wall heat exchangers may be permitted when the antifreeze is of a non-toxic type such as propylene glycol. Safety regulations may call for use of a "double-wall" heat exchanger which provides a double barrier between antifreeze solution and potable water, when toxic antifreeze solutions are used. The closed collector pipe loop must have an expansion tank and a separate pressure relief valve in addition to the valve on the storage tank.

Because collected heat must be transferred through the heat exchanger, the collection fluid must be hotter, and thus this system is somewhat less efficient than one in which domestic water circulates through the collector directly. A check valve in the collector return prevents the migration of heat from tank to collector by thermo-syphon action on cold nights.

Pumped Circulation with Freeze Control. The system shown in Fig. 18 employs a circulating pump, but dispenses with the heat exchanger. Because the collector circuit is not sealed off from the stored water, an antifreeze solution cannot be used. Instead, protection against freezing temperatures is

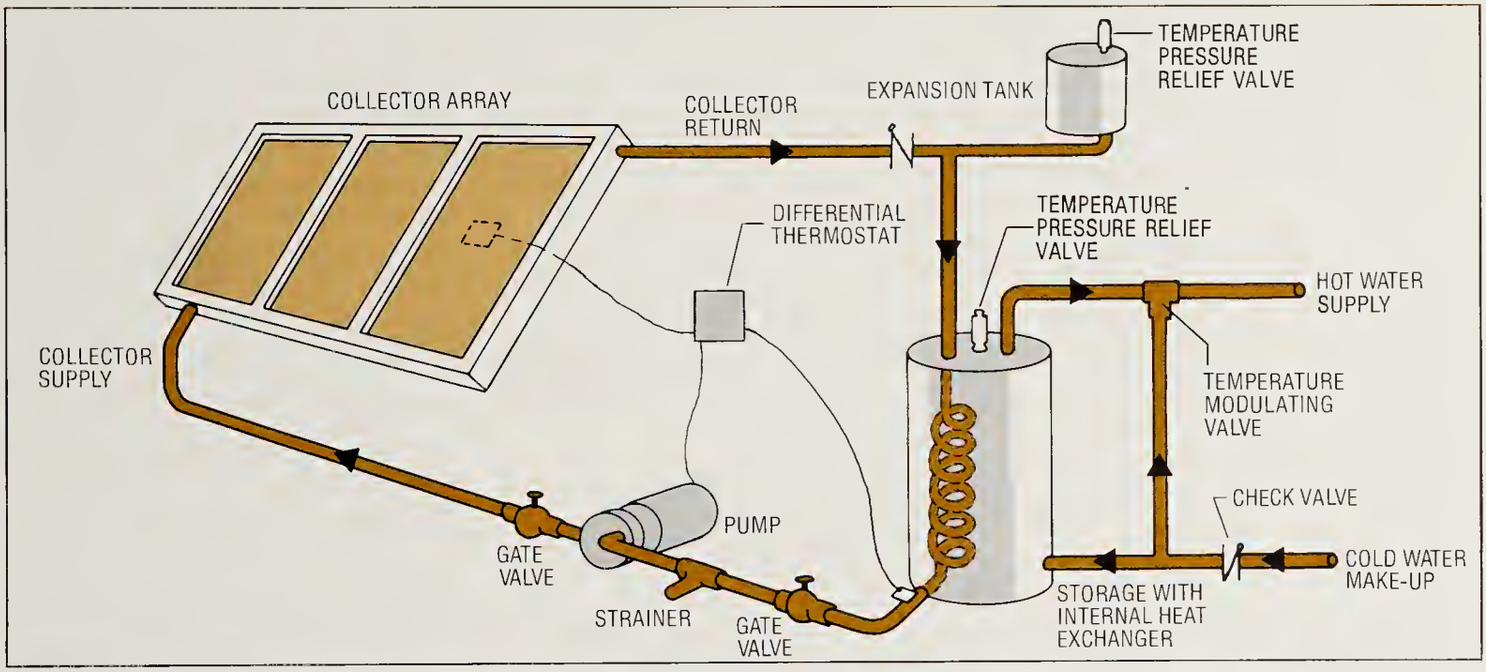


FIGURE 17/ PUMPED DOMESTIC WATER HEATING SYSTEM WITH HEAT EXCHANGER

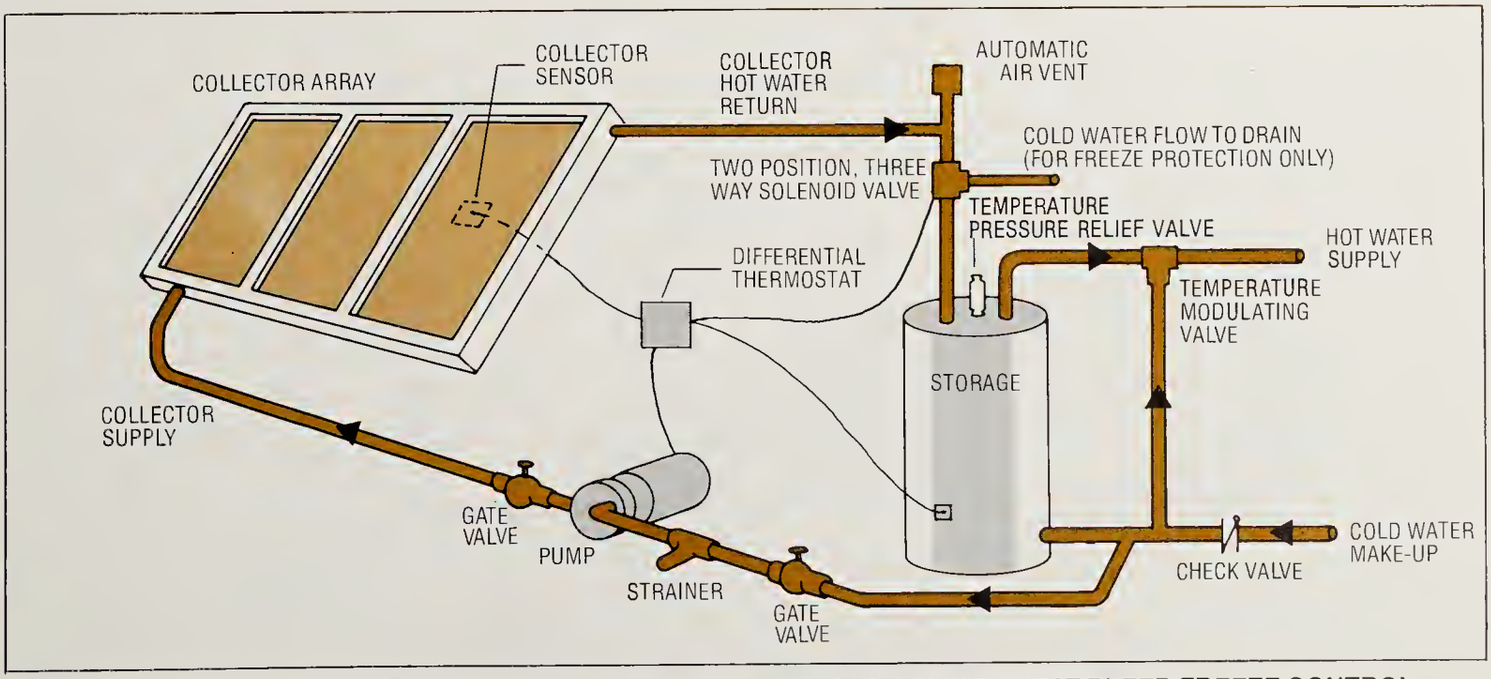


FIGURE 18/ PRESSURIZED/PUMPED DOMESTIC WATER HEATING SYSTEM WITH HEAT BLEED FREEZE CONTROL

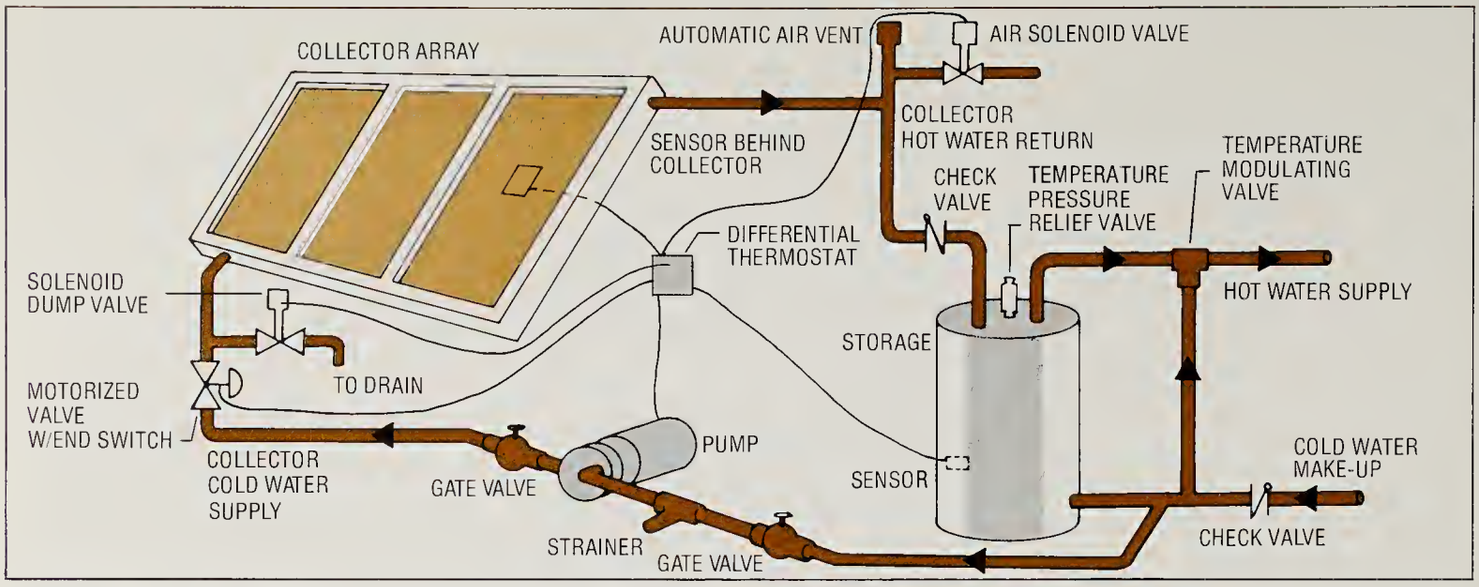


FIGURE 19/ PUMPED CIRCULATION DOMESTIC WATER HEATING SYSTEM WITH DRAINDOWN

afforded by passing cold water from well or city mains through the collector system. The rate of flow of this water is maintained high enough to prevent freezing before it leaves the collector.

A three-way solenoid valve is the key control element in this system. During normal operation, the valve is positioned so that water circulates freely between tank and collector. No cold water is admitted to the system unless a hot water tap is opened somewhere within the building, in which case makeup water enters from the supply source. When freezing temperatures are encountered, the three-way valve automatically cuts off the storage tank and diverts return water from the collector into a dry well or sump. This sets up a constant flow of water from the source through the collector circuit and out to the sump.

Pumped Circulation with Draindown. Fig. 19 shows a third method for providing freeze protection in solar water heating systems. This system, again, incorporates a circulating pump for collector water, but does not employ a heat exchanger. With this method, the collector circuit is drained of water when freezing temperatures appear imminent.

When a temperature sensor affixed to the bottom of the absorber plate detects a drop to about 40°F, it initiates closing of the motorized valve in the collector supply. Reaching its fully closed position, the valve trips an end switch that trips the solenoids of both the dump valve and the air inlet valve. Water then drains freely from the collector circuit and out of the system. Typically, the amount of water drained is not more than two or three gallons including that in all piping exposed to freezing temperatures. The pressurized source water is prevented from flowing to the collector by means of the motorized valve in the supply line and the one-way check valve in the return.

Whenever the absorber plate temperature rises to a pre-set difference above storage, the motorized valve begins to open, the circulating pump restarts, and the dump valve and air inlet valve close. As the collector circuit refills, trapped air is relieved through the automatic vent and normal circulation of collector water is resumed.

Storage: Domestic Hot Water Tank Arrangements

Most applications of solar water heating require a back-up or auxiliary source of heat for periods of low solar availability, or high heat requirements. The manner in which the solar heat and auxiliary heat are employed in a system has a significant effect on the amount of useful solar energy which can be collected and applied to the heating load.

Separate Solar and Conventional Domestic Hot Water Tanks. One of the many proven arrangements for introducing supplementary heat is illustrated in Fig. 20. The larger tank is connected into the collector loop and stores water heated by the sun by one of the methods described earlier. In tandem with the storage tank is a conventional water heater having a fossil-fuel burner or an electric heating element. The outlet line of the solar storage tank is a pipe connected to the "cold" or inlet line of the conventional heater. When there is a demand for hot water somewhere in the

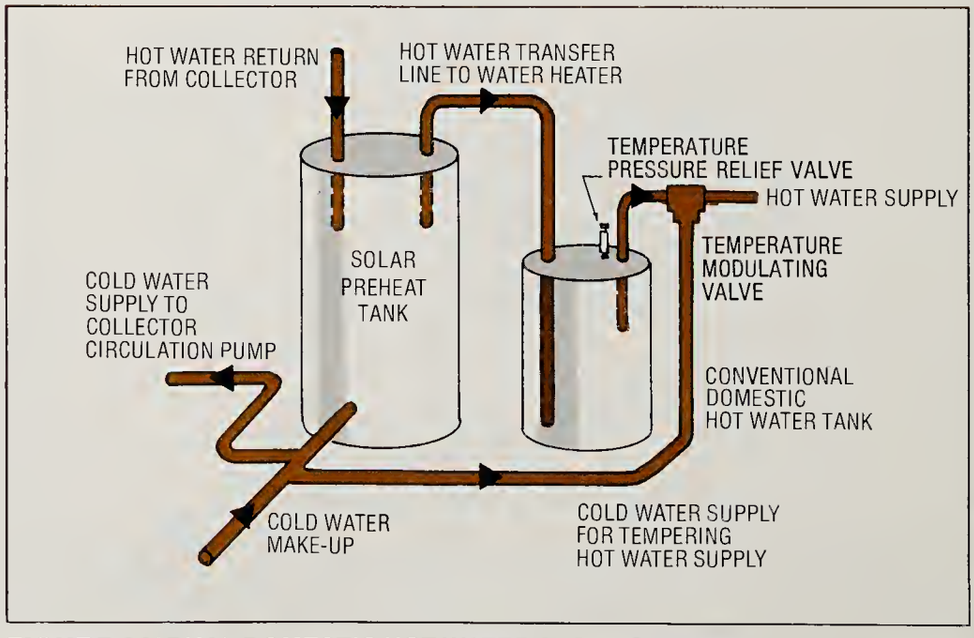

HOT WATER RETURN FROM COLLECTOR
HOT WATER TRANSFER LINE TO WATER HEATER
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY
TEMPERATURE MODULATING VALVE
SOLAR PREHEAT TANK
COLD WATER SUPPLY TO COLLECTOR CIRCULATION PUMP
CONVENTIONAL DOMESTIC HOT WATER TANK
COLD WATER MAKE-UP
COLD WATER SUPPLY FOR TEMPERING HOT WATER SUPPLY

FIGURE 20/ DUAL DOMESTIC HOT WATER STORAGE TANKS

building, city water pressure forces water through the solar storage tank, through the conventional tank, and out to a water tap or fixture.

When the solar-heated water is warm enough it will move through the conventional tank without affecting its thermostat or without requiring additional heat. However, should the conventional tank water drop below a preset temperature, it will cause the thermostat to trip, energizing the burner or electrode of the conventional heater. The heater then continues to operate in its normal fashion, cycling on and off as needed to maintain tap-water temperature at design levels. An advantage of this configuration is that only the relatively colder water in the large storage tank circulates through the collector which, thus, is permitted to function at a higher efficiency.

Single Storage Tank. It is also possible to provide both solar and auxiliary storage in the same tank as shown in Fig. 21. When this system is used, a large storage tank should be selected. The temperature of the auxiliary fuel input should be set to maintain a tank temperature of about 110-120°F. This will mean that the coldest water that can be circulated to the solar collectors will be 110°F unless some natural or artificial means of stratification is achieved in the tank. The primary disadvantage of the system is that because the water temperature which is circulated through the collector is higher than in the previous arrangement, the efficiency of the collector is much lower.

Combined Solar Space and Domestic Water Heating System. Fig. 22 shows the combination of solar space heating with a domestic water heating system. Water in the solar storage tank is warmed in one of the ways described earlier. If the solar storage tank temperature is high enough, cold domestic make-up water passing through a heat exchanger in the storage tank will pick up sufficient heat to avoid drawing energy from the domestic water tank heater. Whenever the temperature of the domestic water tank drops below the storage tank temperature, the domestic water is pumped through the heat exchanger, transferring whatever heat is available. Final temperature boosting, if necessary, of the domestic supply, is provided by an auxiliary heater in that tank.

It is possible to put the heat exchanger in the domestic storage tank and circulate water from the solar tank through it. It is also possible to combine a solar space heating system with a two-tank domestic water heating system, as shown in Fig. 20.

Residential homes, Santa Clara, CA

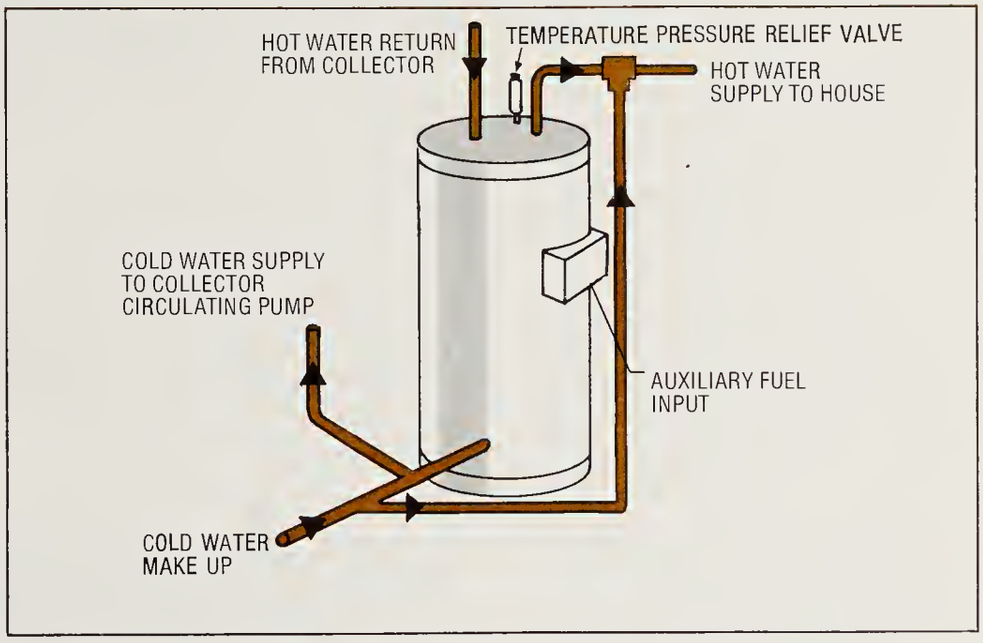

HOT WATER RETURN FROM COLLECTOR
TEMPERATURE PRESSURE RELIEF VALVE
HOT WATER SUPPLY TO HOUSE
COLD WATER SUPPLY TO COLLECTOR CIRCULATING PUMP
AUXILIARY FUEL INPUT
COLD WATER MAKE UP

FIGURE 21/ SINGLE DOMESTIC HOT WATER TANK

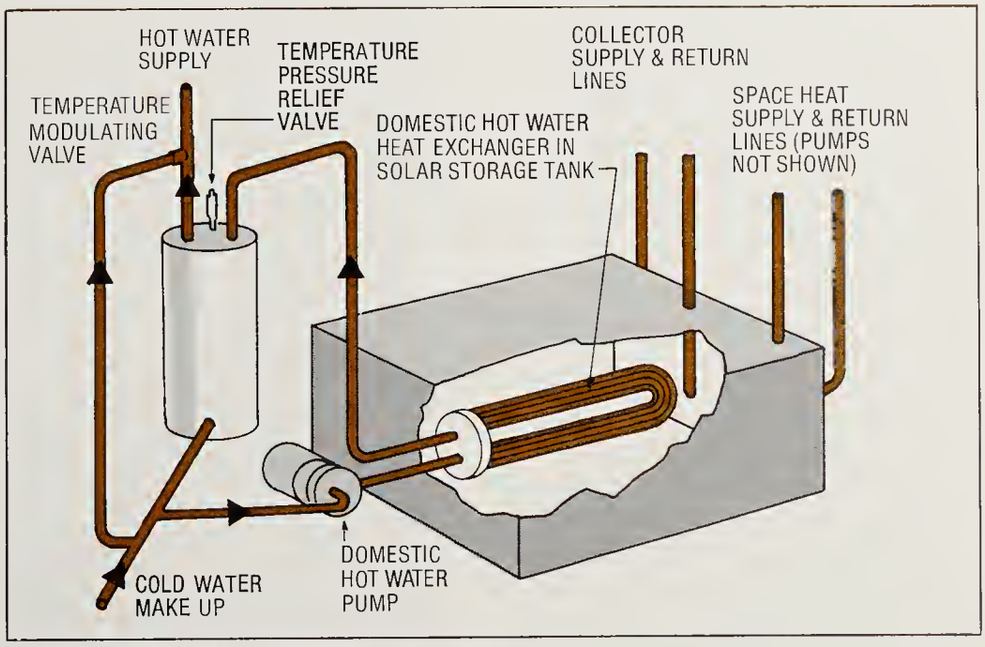

HOT WATER SUPPLY
TEMPERATURE PRESSURE RELIEF VALVE
COLLECTOR SUPPLY & RETURN LINES
TEMPERATURE MODULATING VALVE
DOMESTIC HOT WATER HEAT EXCHANGER IN SOLAR STORAGE TANK
SPACE HEAT SUPPLY & RETURN LINES (PUMPS NOT SHOWN)
DOMESTIC HOT WATER PUMP
COLD WATER MAKE UP

FIGURE 22/ COMBINED SOLAR SPACE AND DOMESTIC WATER HEATING SYSTEM

DISTRIBUTION: SPACE HEATING

System Requirements

Solar energy collected at relatively low temperatures can be used effectively for space heating. However, the design requirements for space heating systems differ from those for domestic water heating, because space heating needs are seasonal and larger. These differences affect the choice of collector type, size and tilt and influence the design of storage and distribution systems as well.

Fig. 23 compares space heating energy demand with collector production over a year's time. Available solar energy is least when heating needs are highest. For this reason it has been found advisable to design solar systems to handle only about 60 to 70 percent of the total annual space heating loads. Systems can be sized to supply the complete winter requirements, but these will not fully utilize collector potential in the summer months and, consequently, may show a poor economic return on first cost investment. A second economic consideration stems from the fact that it is necessary to provide an auxiliary system capable of meeting 100 percent of space heating requirements at times when no solar contribution is forthcoming. Care should be taken, however, that the auxiliary system not be oversized.

Solar collectors for space heating purposes are quite similar to those for domestic water heating. In general, collection temperatures will be higher. Collectors that operate at higher temperatures lose more heat. Thus the use of double glazing may be appropriate in some climates. In climates where freezing is a danger, liquid collection systems must be protected by draining the collectors and related tubing, incorporating an antifreeze solution or other appropriate means.

There is an additional need for high temperature protection in summertime when collectors continue to absorb solar energy even when there is little or no demand for heat in the building. Temperature buildup can be checked by maintaining circulation in the collector loop and incorporating a means for rejecting heat. If circulation is to be stopped in warm weather and temperatures allowed to build, collectors and supporting structures must be engineered to withstand the severe thermal stresses that can result. Whatever the high temperature protection, however, all collectors should be designed to withstand high thermal stress to protect against unforeseen circumstances.

Space heating systems can take many different forms, each with its own particular combination of the various approaches to collecting, storing and distributing solar energy. Four workable systems, each based on a different means of distribution, will serve to illustrate some of the possible combinations. Three of these involve direct distribution of stored heat by pump or blower. The fourth uses a heat pump to boost the level of stored heat to some higher temperature that is more compatible with the design requirements of the chosen space heating system. Three use water as the medium for collecting and storing solar energy, while one uses air as the medium for collecting and solid material for storage.

System 1: Water Collection/Water Storage/Air Distribution.

The system depicted in Fig. 24 and slight variations of it have found wide acceptance because they are simple to operate and control. The circulating pump in the collector loop operates whenever collector temperature is higher than the temperature of storage tank water by a preset amount. When the pump stops, water in the collectors and pipe lines drains into the storage tank. To permit this automatic draining process, the return pipe must be coupled to the tank in such a fashion that the end of the pipe is kept above the level of the stored water or the pipe must be vented by some other means.

When the building thermostat calls for heat, a pump circulates stored water through a heat exchanger coil in the return air duct upstream of the furnace. At the same time, the furnace fan begins to draw air through this heat exchanger coil and into the building. As long as the coil transfers sufficient heat to maintain supply air temperature high enough, the furnace burner or heating element remains inoperative. When the supply of solar heat falls short of the building's requirements, the furnace comes on to furnish supplementary heat.

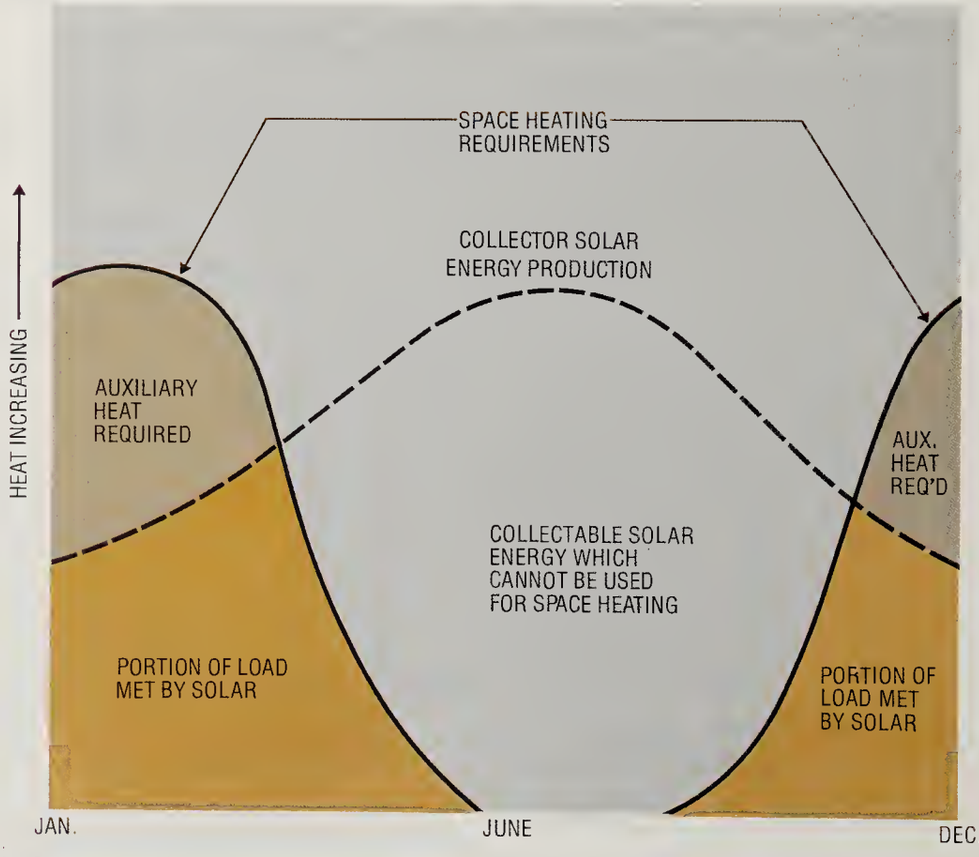


FIGURE 23/ SPACE HEATING DEMAND VS. COLLECTOR PRODUCTION

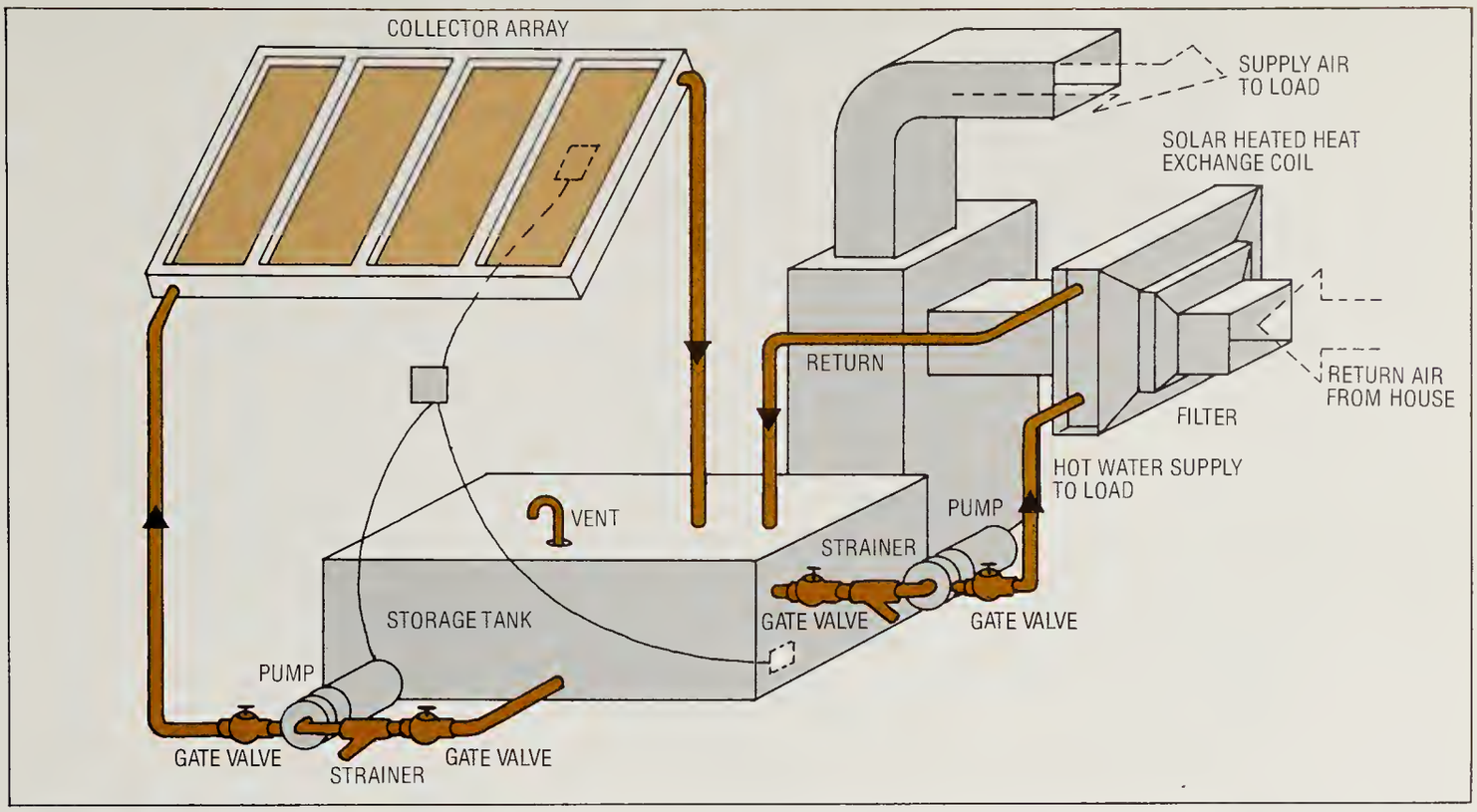


FIGURE 24/ WATER COLLECTION/WATER STORAGE/AIR DISTRIBUTION SPACE HEATING SYSTEM

There are several common methods for control of the input of auxiliary energy. One of these involves the conventional furnace thermostat which normally ignites the burners when bonnet temperature drops below 130°F approximately. Resetting the furnace bonnet temperature to about 100 to 110°F should be considered for improved economy. The furnace fan operates for a slightly greater period of time, but more benefit is derived from the solar system because it is useful at lower temperatures. Reducing the bonnet temperature still further during the spring and fall seasons can save additional energy.

A second method uses a two-stage thermostat with the first stage controlling solar heat alone and the second, solar and auxiliary heat. When the thermostat calls for heat, the first stage is activated. If it is incapable of meeting the heating requirement, the second stage activates the auxiliary heat.

This system could be modified somewhat by the addition of three-way valves to circulate water directly from the collector array to the house heat exchange coil when heat is available in the solar collectors and there is a simultaneous space heating requirement. This would bypass the storage tank and eliminate the necessity of raising the temperature of the entire volume of the storage tank to a usable temperature before the solar energy can be utilized. This modification to the system would require additional sensing and control capabilities. In most instances the primary heating demand occurs during non-collection hours and with a properly sized storage volume the benefits added by this modification will probably be minimal.

System 2: Water Collection/ Water Storage/ Water Distribution.

Solar energy systems using water collection and storage are highly suited for fin tube and radiant panel installations. Finned-tube convectors, however, normally require a higher water temperature than fan-coil units to achieve an effective heat exchange. To compensate for the lower temperatures of solar heated water, therefore, it is usually necessary to specify a greater amount of tube than would normally be installed.

When finned-tube convection devices are used for heat distribution, there are two possible configurations:

Fig. 25 shows a *series* configuration, in which heat is supplied by either the solar system or the auxiliary boiler. When the solar storage tank is hot enough to supply the heating load, water is pumped from the storage tank through the finned tubes and bypasses the boiler. If the storage tank is not hot enough to supply the heating load completely, water is pumped through the boiler and then the finned tubes, bypassing the storage tank.

It is not advisable to pump water from the storage tank, through the boiler and then through the finned tubes. This type of arrangement would actually use less solar energy and more auxiliary energy than the one described below.

The inset on p. 18 shows a parallel distribution configuration, in which heat can be supplied by both the solar system and the auxiliary boiler simultaneously if necessary. If the heating requirement can be supplied by the water from the solar tank, the auxiliary boiler does not operate. When more heat is required than the solar system can supply alone, the auxiliary boiler begins operating, supplementing the solar heat. This arrangement permits lower temperature water in the solar system to be used to supply a portion of the heating load. The result is higher collector efficiencies, and more usable solar energy.

Larger systems sometimes employ outdoor-air temperature sensors to control boiler water temperatures. This feature provides flexibility in meeting fluctuations in the building's heating load imposed by changing weather conditions. When outdoor temperature drops, for example, boiler water temperature is raised automatically to compensate for increased heat load from the building. Like System I, the hydronic system can be modified to allow collector water to be

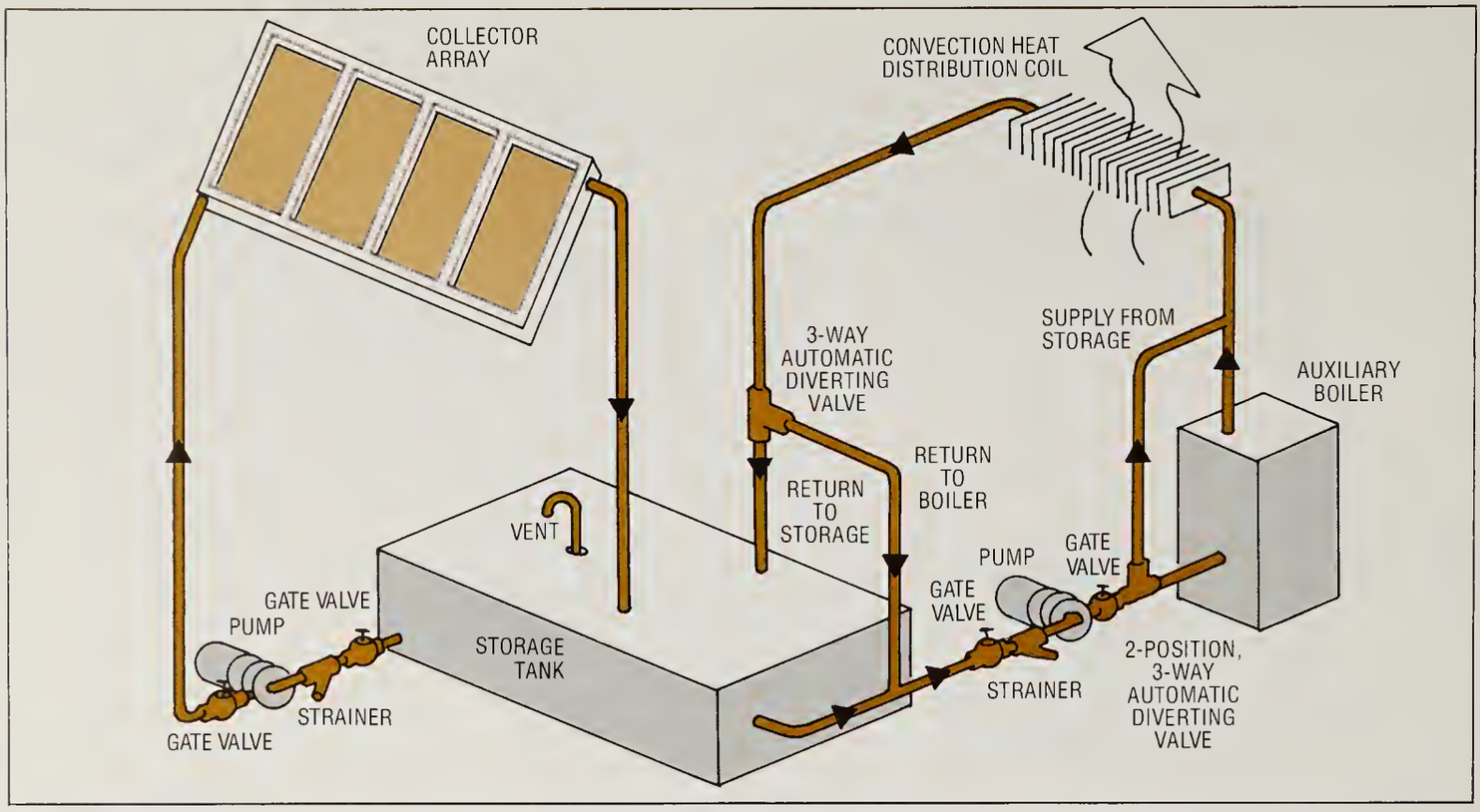
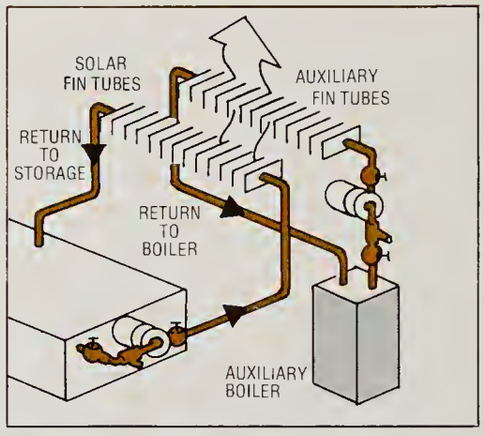


FIGURE 25/ WATER COLLECTION/WATER STORAGE/SERIES WATER DISTRIBUTION SPACE HEATING SYSTEM

pumped directly to convectors and radiant tubes, thus bypassing the storage tank.

Even more compatible with the characteristics of water collection and storage are radiant panel heating systems employing copper tube embedded in concrete floor slabs and in wall and ceiling construction. Such radiant systems operate with lower fluid temperatures and, consequently, the utility of the solar heated water will be higher. Such a system is represented in Figure 26.

Experience dictates that the maximum surface temperature for a ceiling or wall radiant heating system is 120°F; for a floor panel, 85°F. Because of the higher distribution temperatures available, wall and ceiling radiant heating systems require less panel area than a floor panel, in order to meet the same load. However, any calculation of heat transfer from a radiant panel heating system to the room air must consider both the convective and conductive heat transfer rates. Technically, transfer of heat by convection is 0.4 Btu (per hr. per sq. ft. per 1°F) for a ceiling panel, 0.8 Btu for a wall panel, and 1.1 Btu for a floor panel. In addition, there is the transfer of heat by radiation, which is



PARALLEL DISTRIBUTION

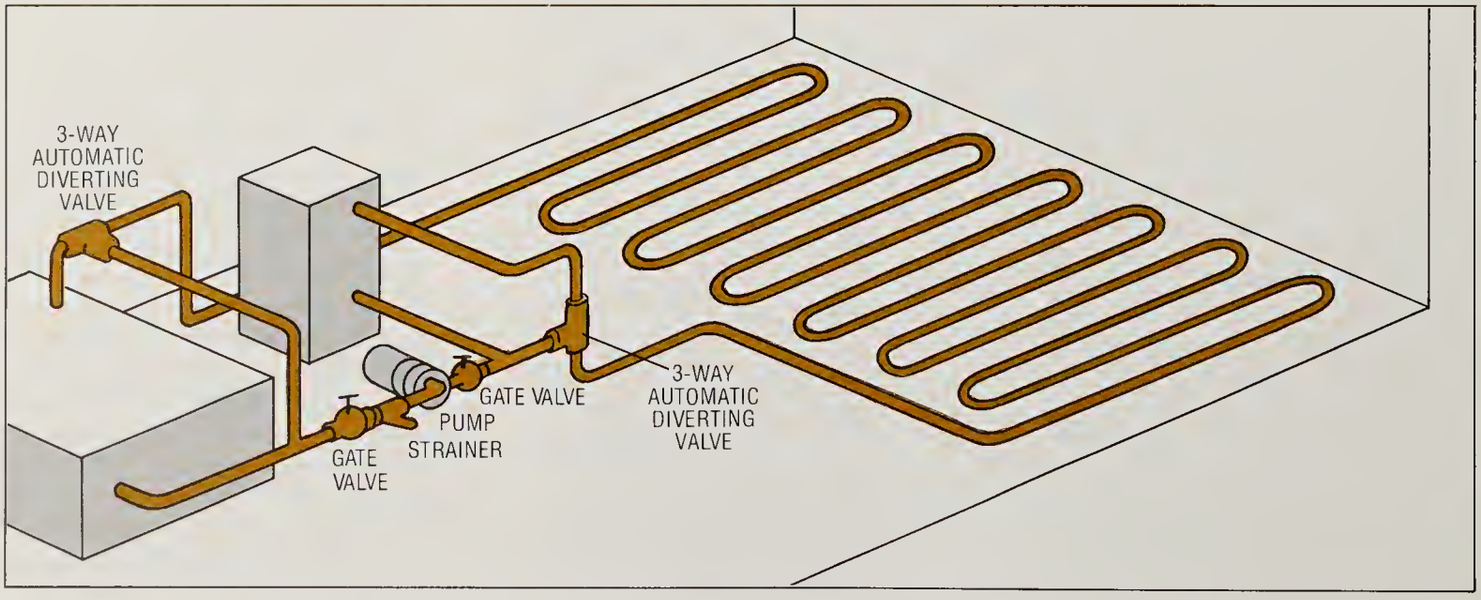


FIGURE 26 / WATER COLLECTION / WATER STORAGE / SOLAR RADIANT HEATING

typically about 1.0 Btu for all three distribution types. Therefore, the sums of heat transfer are 1.4 Btu for a ceiling panel, 1.8 Btu for a wall panel, and 2.1 Btu for a floor panel. These rates must, in turn, be multiplied by the surface-to-air temperature difference for the hourly heat transfer in Btu per square foot of panel area.

Floor installations have been the most common, with copper coils embedded in concrete, having one inch or more of concrete above and never less than one-half inch below. For slab on grade construction, insulation is imperative beneath the slab. It is also important to insure that ground water will not also carry away heat. Floor panels are particularly appropriate for structures with high-ceilings.

Ceiling and wall panels are usually embedded in plaster. Centering the coils between rooms or floors is not recommended, as it usually results in poor heat transfer and lack of room temperature control. For wall panel installations, very heavy insulation is necessary to reduce heat loss to the exterior from the warm walls.

Conventional hot water heating controls are appropriate, and air vents should be installed at the system high points. Drain cocks should also be provided at system low points. One-half inch Type L copper tube is often an appropriate size.

System 3: Air Collection/ Solid Material Storage/ Air Distribution.

Air may be appropriate as the heat-transfer fluid in systems where the primary use of the energy is for the heating of living spaces. Air collection systems have several distinct characteristics when compared to circulating liquid collection systems:

- Air collectors are somewhat less efficient, requiring a greater area of solar panels.
- Rock storage requires greater volume than water because of its lower heat capacity, and the requirement for space around the rocks to permit the circulation of air. About 0.5 cubic feet of storage should be allotted per sq. ft. of collector (or about 2-3 times the requirement for water storage).
- The collector supply and return ducts must be large enough to accommodate a flow of about 2 SCFM (Standard Cubic Feet per Minute) of air/sq. ft. of collector. For most residential applications, this will necessitate an area of 3-5 square feet.
- Since large quantities of air must be circulated, and since there is a pressure drop through both the collectors and the storage container, greater fan motor horsepower may be required than pump motor horsepower in comparable water systems, reflecting higher costs.
- It is quite important to have a relatively clean, dust-free collector to maintain efficiency and reduce pressure drop. A high quality filter which is regularly cleaned is important.
- It is important to waterproof the outside of the rock storage container to prevent the penetration of ground water. A warm, moist storage container is very conducive to the formation of fungi which can reduce air flow and distribute allergy-irritating spores through the house distribution system.
- Since the transfer of heat from air to water is not as efficient as from water to water, larger heat exchangers will be required to heat domestic water supplies.
- It is important to provide an air plenum above and below the storage container to permit a uniform flow of air. It is also necessary to flow warm air down through the storage container for collection, while distribution requires reversing and flowing up through storage.

Fig. 27 illustrates a typical air collection/rock storage/air distribution system.

When heat is available for collection, and there is not a simultaneous demand in the house, the collector circulation fan begins operation drawing air down through the storage container. Motor operated damper number 3 is open whenever the collector fan is operating and closed at all other times. The

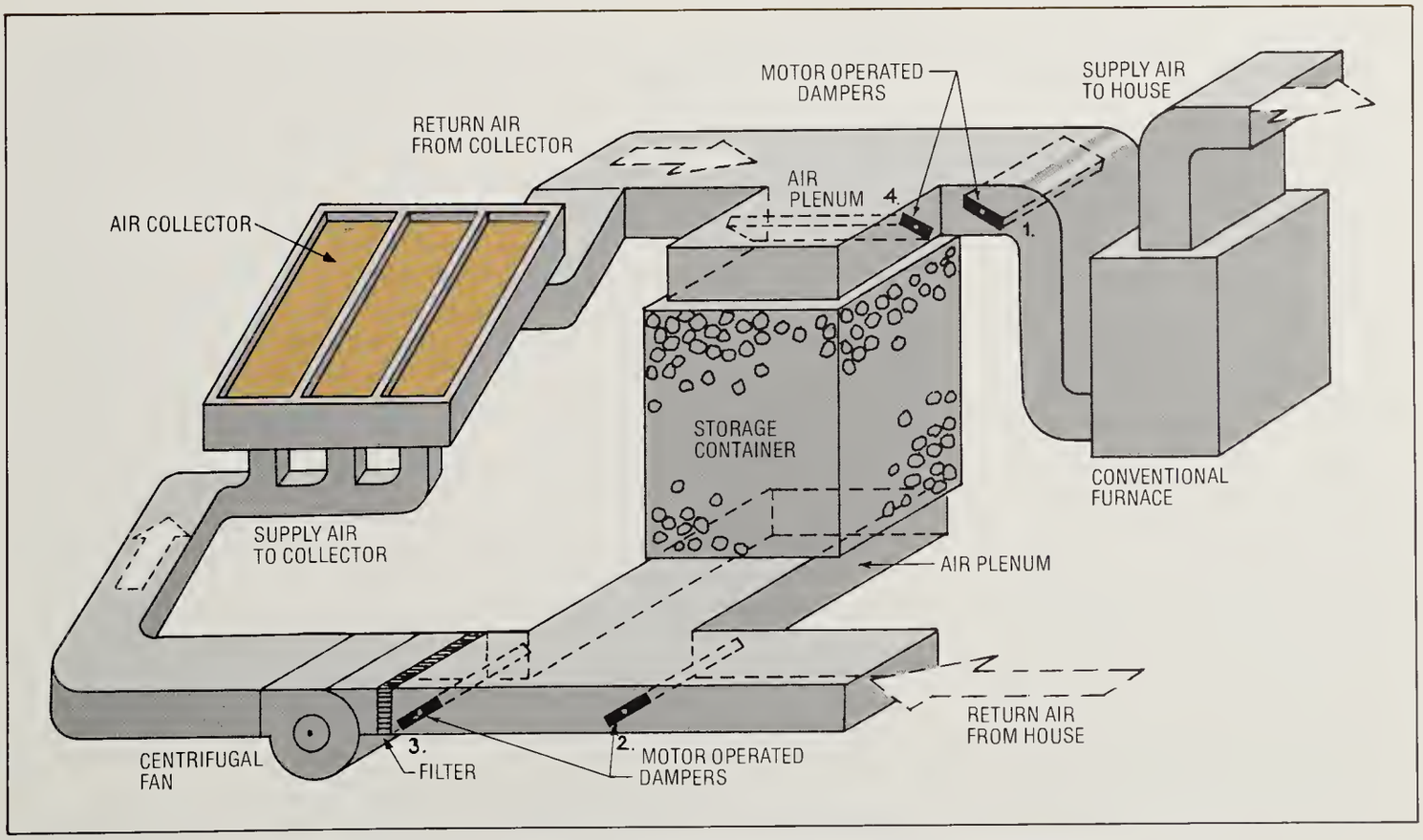


FIGURE 27/ AIR COLLECTION/SOLID MATERIAL STORAGE/AIR DISTRIBUTION SPACE HEATING SYSTEM

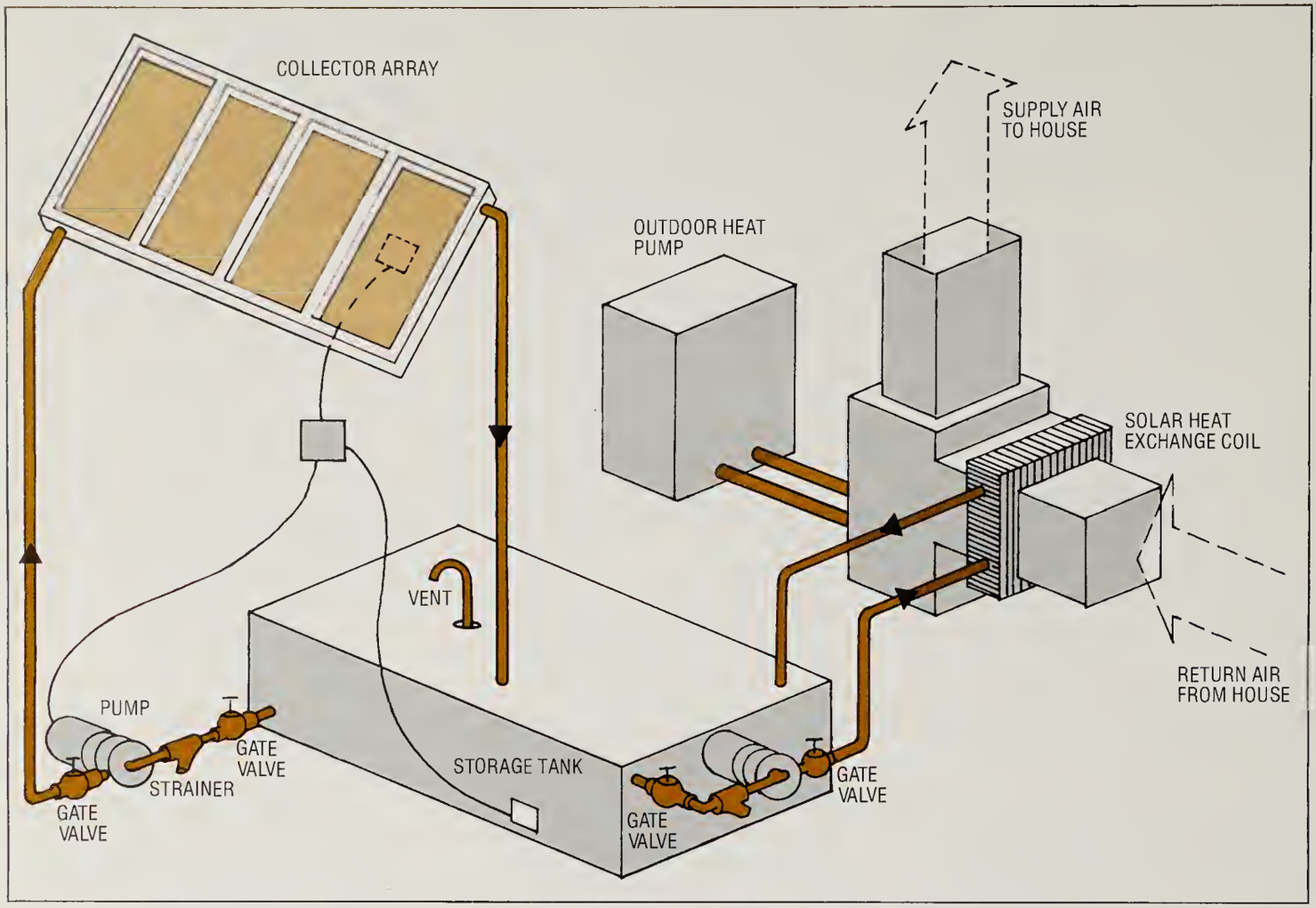


FIGURE 28/ WATER COLLECTION/WATER STORAGE/AIR-TO-AIR HEAT PUMP DISTRIBUTION SPACE HEATING SYSTEM

top portion of the storage container contents will heat first, and the heat will extend downward as more energy is collected. Motor operated damper number 4 is normally open.

When heat is required by the space, but no heat is being collected, the centrifugal fan in the furnace begins operation, signaling dampers 1 and 2 to open. (These dampers are closed unless this fan is operating). Return air is drawn upward through the storage, exiting at maximum temperature, and circulated to the house. Auxiliary energy is not added by the furnace unless the heating load cannot be provided by the solar system.

If there is a simultaneous collection of energy and demand for heat by the house, motor-operated damper 4 is closed. This damper is open unless both collection and distribution fans are operating simultaneously. Air is thus circulated directly from the collector to the house. This is more important in air-rock systems since the heat transfer into and out of storage is not as fast or efficient as water collection, water storage systems.

System 4: Water Collection/ Water Storage/Heat Pump Distribution.

Energy in the form of heat flows "downhill" from a warmer substance to a colder substance. The rate of flow is proportional to the thermal gradient, which is the temperature difference that exists between the warmer and colder materials. Therefore, the ability of a solar-heated fluid to feed energy into a space heating system depends on the thermal gradient between the solar-heated storage source and the air or water circulating in the heating system. As heat is taken from it, the stored water experiences a continual drop in temperature until a point is reached when the diminishing thermal gradient is insufficient to provide the flow of energy needed by the structure's space heating system.

In the three systems just described which make direct use of solar-heated storage, the thermal gradient may become inadequate to provide sufficient heat when storage temperature drops to, say, 90°F. The exact temperature for any system depends on whether that system is hydronic or ducted air, the type of heat delivery equipment (finned-tube baseboard, fan-coil units, etc.), and the indoor design temperature. In any case, there is a low point at which the thermal gradient becomes insufficient, and supplementary heat must be introduced.

The electrically driven heat pump offers a means of enhancing the flexibility and efficiency of solar systems. It has the capability of extracting heat from a cooler source and pumping it up to a higher temperature, thereby increasing the thermal gradient. This makes it possible to extract useful heat from the solar storage system even when its temperature has fallen below the room temperature.

Heat pumps most commonly used in small commercial and residential projects are of two types:

1. *Air-To-Air Heat Pump*–When heating is required, the heat pump extracts heat from one air source (usually the outside air), pumps it up in temperature, and warms the room air.
2. *Water-To-Air Heat Pump*–When heating is required, the heat pump extracts heat from the storage

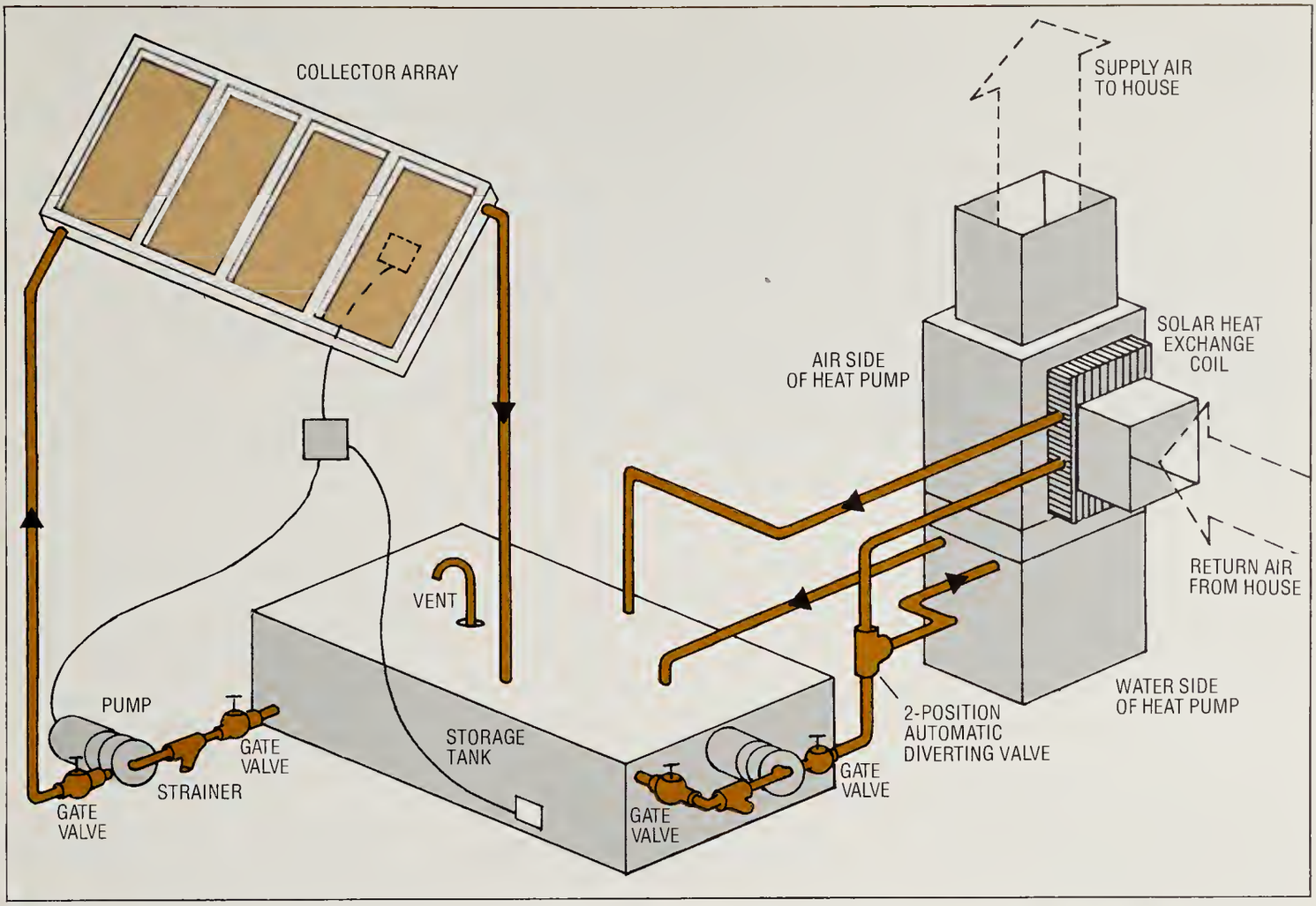


FIGURE 29/ WATER COLLECTION/WATER STORAGE/ WATER-TO-AIR HEAT PUMP SPACE HEATING SYSTEM

water, pumps it up in temperature and warms the room air.

The heat pump is essentially a heat-transfer refrigeration device that puts the heat rejected by the refrigeration to good use. It is similar in design to a conventional refrigeration machine and has the same three basic components: compressor, condenser and evaporator. The uniqueness of the heat pump lies in its reversing valve which permits changing the direction of refrigerant flow. Because of the reversing valve, all heat pumps currently manufactured can provide cooling as well as heating. For space cooling, the process is the reverse of that described above.

Air-to-air heat pumps can be used in solar systems in several different ways. The simplest arrangement is similar to that shown in Fig. 28 All solar heating is done directly from storage, without the aid of temperature "boosting" by the heat pump, using the fan unit of the heat pump to circulate the room air over the solar heat exchange coil. If the heat available from the solar storage is insufficient, the heat pump begins to operate, supplying additional heat to the air. Although this configuration does not permit the stored solar energy to be used below the space temperature, it greatly reduces the operational time of the heat pump, saving the electricity needed to operate its compressor. Other heat pump configurations are possible which permit the air-to-air heat pump to extract heat from water or solid storage at temperatures below the room temperature. These systems are more complex, however, and they require additional automatic controls. Unless they are carefully designed, they may not save as much energy as other solar heating systems.

Water-to-air heat pumps can also be used in solar heating systems as illustrated in Fig. 29. When the solar storage tank temperature is over a certain point (usually about 90°F), storage is used directly for space heating with the heat pump fan circulating the room air over the solar water coil. When the storage tank temperature falls below the temperature needed for direct heating, the control valve changes position and circulates the storage water into the heat pump.

When the water flow to the heat pump has been proven by a flow switch, the heat pump compressor begins to operate, extracting heat from the water and pumping it up in temperature. It is then used for warming the room air. This continues until the heating load has been satisfied or the storage tank temperature drops to the lower operating limit of the heat pump (usually about 60°F). The actual operating temperature limits of the heat pump must be determined by the manufacturer and the solar system controls set accordingly. If another water supply of appropriate temperature is available, it can be used when the usable heat in the solar tank has been exhausted. It is usually necessary to supply a back-up heat source, such as electric resistance coils built into the heat ducting, to provide heat when the solar tank and other heat sources have been depleted.

Used in this way, the solar system improves the actual performance of the heat pump by decreasing the thermal gradient through which it must pump. This reduces both the operating time of the heat pump, and its electrical consumption during operation. Water-to-air heat pumps are often used in applications which have multiple zones in the building, and may require simultaneous heating and cooling in different zones.

SECTION 6

DESIGN RECOMMENDATIONS

Bank, Concord, NH

Introduction

All parts of the solar energy system must be carefully selected in order to obtain the best possible performance. Although most materials used in solar heating and cooling systems are well known to the construction trades, they must be chosen and assembled with special consideration for the unusual operating conditions under which the solar collectors and the associated plumbing system operate.

Absorber Plates

Copper, steel, aluminum and plastic are used for solar collector absorber plates. Copper has, by far, the longest and most successful history of use in this application.

The most important characteristics for absorber plate material are thermal conductivity, corrosion resistance, ease of fabrication, mechanical strength and availability. The absorber plate must also readily accept the desired absorptive coating.

The thermal conductivity of an absorber plate should be high enough to conduct heat to the transfer fluid with a relatively small temperature drop. It is common practice to limit this temperature drop to 10 to 15 °F or even less. Generally, this heat transfer is controlled by four factors: 1) thermal conductivity of the plate material; 2) plate thickness—thicker plates conduct more heat, but tend to be more expensive, heavier, and of slower response, especially at low sun conditions; 3) tube spacing—tubes spaced closer together permit the absorber plate to be thinner when highly conductive materials are used; and 4) the thermal conductance of joints which occur between components. The thermal conductivity of copper (Copper No. 110) is 226 BTU/Hr./Ft.^{2}/Ft./°F. If we set this value equal to 100, the corresponding conductivity for aluminum is about 54, and for carbon steel, about 12. This thermal advantage of copper is summarized in Figure 29, which shows how, under typical conditions, thinner gauges of copper transfer the same amount of heat as thicker gauges of the other two metals. Since plastic acts as an insulator rather than a conductor, its use in absorber plates is limited to low temperature, non-critical operations.

The excellent corrosion resistance of copper in both all copper and mixed-metal systems, in addition to its superior thermal conductivity, have made it the most desirable metal presently used for absorber plates and fluid passages in flat plate solar collectors. Copper is readily available in various types of tube, fittings, and sheet materials which are easily fabricated or joined by brazing, soldering, and mechanical fastening. The handling and fabrication of copper are familiar to the heating, ventilating and air conditioning trades, as well as to the other building trades. Copper has been widely used for roofing, plumbing, and HVAC systems since metals were first employed in these applications.

Copper has the needed mechanical strength, particularly at the elevated temperatures developed in absorber plates. In addition, copper readily accepts a wide variety of selective and non-selective surface coatings.

Absorber Plate Coatings

In addition to durability, the most important properties of absorber plate coatings are absorptance and emittance. The collector plate should absorb as much of the incident solar radiation as possible for maximum efficiency and performance. Surfaces which absorb radiation also "re-radiate" or "emit" a portion of the energy. Limiting this emission or re-radiation of long wavelength energy improves the collector efficiency. A low emittance is especially desirable at high collection temperatures, but absorptance should not be sacrificed to obtain low emittance.

Coating stability, particularly at high temperatures, is important. A coating that has not been proven for solar absorber application might outgas volatile substances which can haze the glazing

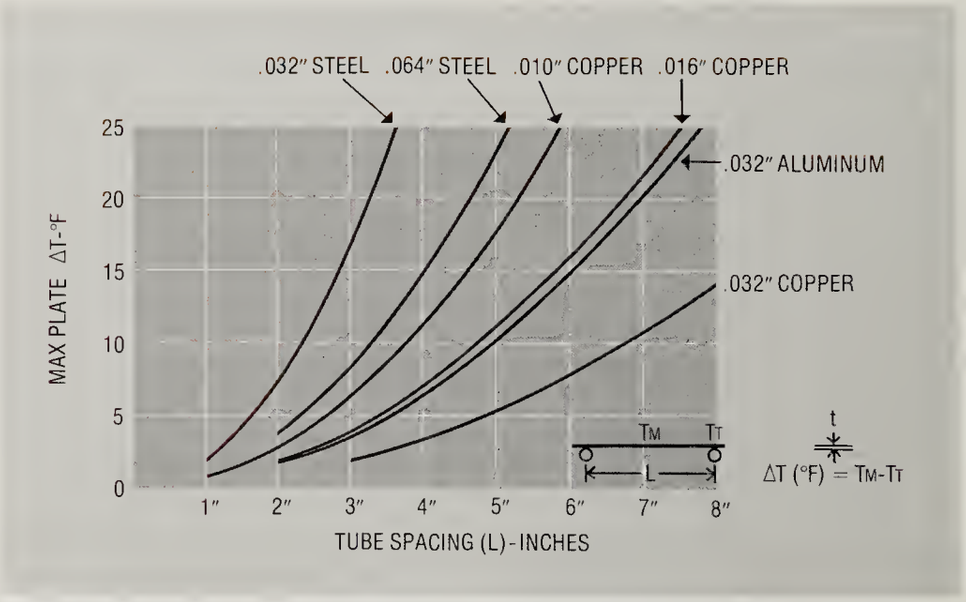


FIGURE 30/ FLAT PLATE SOLAR COLLECTOR ABSORBER PLATE DESIGN PLATE THICKNESS, TUBE SPACING AND ΔT@ 150 BTU/HR-SQ. FT.

covers and lower solar energy transmission, thus reducing collector efficiency. The absorber coating must also prove stable in the presence of moisture, and provide durability for the life of the collector.

A high performance flat black paint has an absorptance of about 0.95, and about the same emittance. Several commercial flat black paints are suitable finishes for most collector absorber plate applications. Copper absorber plates, properly cleaned, are easily painted, either on site or in the factory where the collector is assembled.

Selective surface coatings have been developed which combine the desired surface properties of high absorptance and low emittance. Copper surfaces can be made selective both by chemical treatment and by electroplating. Commercially available selective surfaces of both these types have emittance values substantially lower than their absorptance as shown in Table 2. Selective coatings are particularly beneficial in applications where collectors operate at higher temperatures. The selective surface minimizes re-radiation from the collector plate to the cover glazing. In this way, heat losses upward from the collector plate are controlled, effectively increasing collection efficiency. Selective surfaces are generally more expensive than flat black paint coatings. Their potential benefits should, therefore, be evaluated before specifying their use.

	ABSORPTANCE	EMITTANCE
1. Flat Black Paint, as applied	.95	.85-.95
2. Commercial Selective Coating (chemical treatment)		
Samples from collector manufacturer A	.86	.09
Samples from collector manufacturer B	.83	.11
3. Typical Black Chrome on Copper	.93-.96	.08-.11

TABLE 2/TYPICAL PROPERTIES OF COPPER ABSORBER PLATE COATINGS

Piping Systems

It is imperative that the fluid passages in the absorber plate be compatible, from a corrosion standpoint, with the materials used for the piping, storage tank, pump and valve bodies. Conventional hydraulic calculation methods are used to size piping in collector arrays. To avoid erosion corrosion, flow should not exceed 4 to 6 feet per second. Pipe runs should be as short and straight as possible, free from built-in "air-locks" that entrap air bubbles which restrict or cut off flow. Connections from the supply and return water lines to the collectors should provide for thermal expansion in each piping loop.

All piping should be pitched from the high point of the system to insure complete drainage when necessary. In systems protected against freezing by draining, the piping is pitched at a minimum of 1/8-inch per 1-foot of run so that the fluid drains completely.

Start-up of all liquid-carrying systems should include a flushing operation to remove all dirt and debris accumulated during installation. Follow manufacturers' recommendations when flushing systems which use a heat transfer fluid other than water.

Corrosion Protection

Solar systems can be expected to have a long, useful life, if proper steps are taken to control corrosion. There are three primary areas of concern in metal collector systems: 1) corrosion between dissimilar metals; 2) use of corrosive liquids; 3) presence of air in the system.

When dissimilar metals are used in the presence of moisture, corrosion can occur. When copper is combined with most other metals, such as aluminum or steel, in the presence of moisture, the copper will not corrode. The other metal will, however, experience accelerated corrosion in a water system. For example, if copper tube is used to connect aluminum collectors, the collectors would soon develop pits in the aluminum fluid tubes, which may cause leaks.

In a solar collector system, as in any system involving a circulating fluid, it is not sufficient simply to use dielectric fittings to separate the dissimilar metals from direct contact. Copper ions can be carried by the fluid and deposited on the other metal, causing pitting. It is difficult, as a practical matter, to exclude bronze valves and pump impellers from collector systems, especially considering the possibility of system modification or repair once in service. Although complex systems of corrosion protection are available for mixed-metal systems, the best solution simply is not to mix metals.

Copper is highly resistant to corrosion when recommended plumbing practices are followed.[1] It is especially resistant to corrosion in re-circulating hot water. There are, however, some unique circumstances which can cause corrosion in copper systems. Some liquids commonly used as heat transfer fluids can lead to corrosion in solar energy systems. Also, some localities are supplied with aggressive waters which can promote pitting corrosion in metal collector systems. Such aggressive waters typically are highly mineralized, having a high level of dissolved solids content including sulfates and chlorides, pH values ranging from 7.3 to 7.8, high (over eight parts per million) carbon dioxide content and the presence of dissolved oxygen gas. A trouble free history of copper plumbing in a locality can usually be taken as evidence that its water is not aggressive to copper. It may, however, be aggressive to other metals. In the absence of such evidence and in undeveloped areas, the water should be chemically analyzed. A qualified water treatment engineer should prescribe a treatment to make problem water non-aggressive to plumbing materials. In general, this involves raising the pH and neutralizing the free carbon dioxide.

If anti-freeze is added to the water, or if special heat transfer fluids are used, new possibilities for corrosion arise. Anti-freezes are formulated products which usually contain corrosion inhibitors. With use, inhibitors may degrade, particularly at high temperatures. The fluid then becomes corrosive and must be monitored and replenished when necessary. Recommendations of the anti-freeze manufacturer should be carefully observed to avoid system damage. Two major types of anti-freeze presently used with water in solar collector systems are propylene glycol or ethylene glycol based.

Ethylene glycol has found major applications in industrial and automotive use. It is available in both inhibited and uninhibited grades. Ethylene glycol formulations with extensive inhibition are used for automotive freeze protection. Less inhibited solutions are generally used for industrial applications. There is a long history of successful use with copper and copper alloys, especially in the automotive radiator. Inhibitors can be regenerated via controlled additions of constituents based on standard tests for pH, alkalinity, phosphates, nitrates and organic matter.

[1] Recommended plumbing practices are described in the Copper Development Association Inc. publication "Copper Tube Product Handbook" (No. 404 0)

Propylene glycol is claimed to be non-toxic. For commercial use, the Food and Drug Administration requires propylene glycol solutions where contact with food products occurs. The 10% inhibited propylene glycol solution, known as Food Freeze #35, meets FDA requirements. The use of additives (including water) may remove FDA Certification. There are presently no standard kits for monitoring propylene glycol chemistry. Since the solution involves only one or two inorganic inhibitors, laboratory tests for solution control focus on pH, alkalinity, and inhibitor concentration. Generally, inhibited propylene glycol, not ethylene glycol, should be used in solar heating systems for domestic water, unless a double walled heat exchanger is employed. For space heating purposes only, inhibited ethylene glycol may be used, if there is not a possibility of cross connections or back flow into the household plumbing system or building supply.[2]

Propylene glycol is quite corrosive to aluminum, especially in the presence of either copper or brass. It will superficially attack copper but the attack is uniform as opposed to concentrated pitting.

In summary, many anti-freeze solutions require the addition of inhibitors and buffers for pH and corrosion control. In selecting inhibitors for glycol solutions, avoid oxidizing agents, such as chromates, which tend to promote rapid degradation.

Periodic monitoring, especially of pH, is required, with eventual solution replacement when the buffers are expended. Mixed metal systems should be avoided whenever glycol solutions are used. It is advisable to install filters to remove solids that may develop in the system.

Draindown systems provide protection from freezing by draining the liquid from areas which experience freezing temperatures. When draindown systems are used, special care should be taken in selecting the metals used in the system. Copper collectors and piping will withstand repeated exposure to air and water without difficulty. Aluminum and steel are much less resistant to the corrosive effects of alternating exposure to water and air.

Collector Cover Glazing

The number of cover plates chosen depends on the desired collector operating temperature and performance. Although additional cover layers reduce heat loss, they also reduce transmission of solar energy. There is a point where additional glazing actually di-

[2] Local regulations must be observed.

MATERIAL	THICKNESS (INCHES)	SOLAR ENERGY TRANSMISSION (%)	MAXIMUM OPERATING TEMP (°F)
Clear Lime Float Glass	1/8	85.0	
	3/16	81.0	400
	1/4	78.0	
Water White Crystal (Low Iron) Glass	1/8	91.0	
	3/16	90.5	400
	1/4	90.0	
100% Acrylic Colorless Cast Sheet	1/8	89.0	
	3/16	87.0	190
	1/4	85.0	
Polycarbonate	1/8	81.0	
	3/16	78.0	270
	1/4	74.0	
Tedlar Film	0.004	93.5	227
Filon 388	0.060	82.0	
(Flat) 548	0.030	86.0	220
608	0.080	77.0	
Teflon Film	0.002	97.0	400
Mylar Film	0.001	85.0	220
Kalwall Sunlight Regular	0.025	93.0	140
Kalwall Sunlight Premium	0.040	86.0	140
Lexan Film	0.005	94.0	270
	0.007	93.0	

TABLE 3/SOLAR COLLECTOR COVER MATERIALS

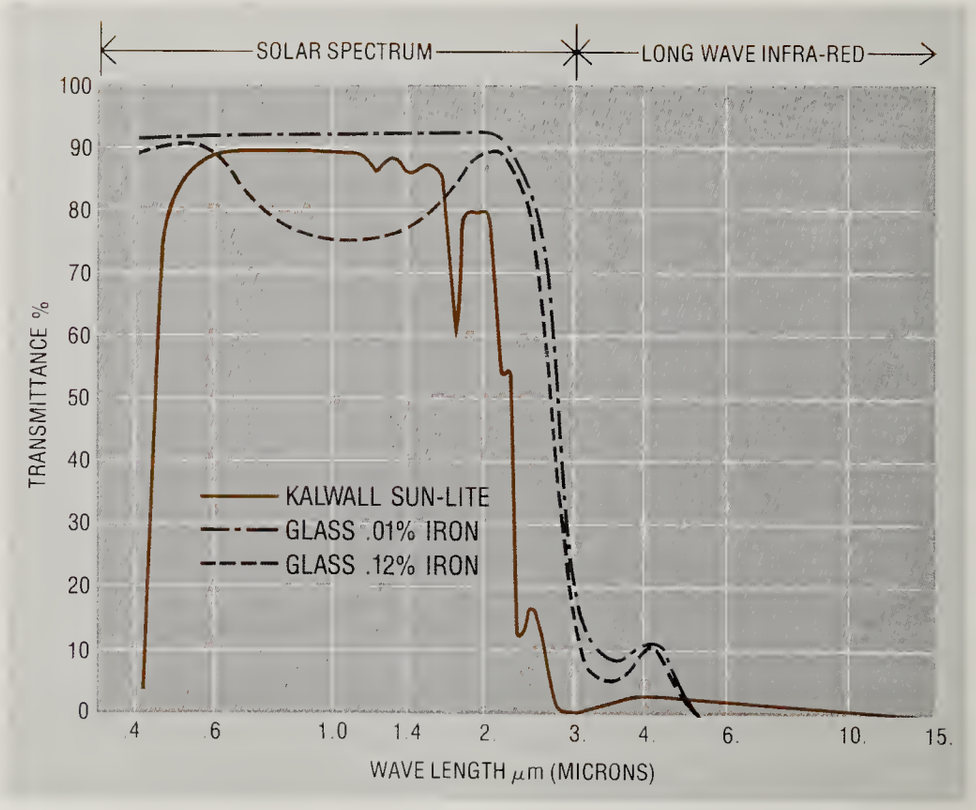


FIGURE 31/ SPECTRAL TRANSMITTANCE OF COVER PLATE MATERIALS

minishes collector efficiency. As stated in Section 2, there are some low-temperature applications where the choice of an unglazed collector is appropriate. In most cases, however, one or two covers are required. A listing of cover materials and their properties is shown in Table 3.

When using glass cover plates, tempered glass with ground edges should be specified and the manufacturers' recommendations regarding maximum permissible spans should be followed. Low-iron-content glass offers high solar energy transmittance, as well as resistance to reverse transmission of long-wavelength radiation from the absorber plate. Tempered glass has good impact resistance, and is stable under ultraviolet and high temperature conditions.

Cover-to-cover and cover-to-absorber plate seals must be tight, otherwise, dust, dirt and moisture will migrate to the collector interior through breaks caused by thermal movement. If two glass plates are hermetically sealed, they must have the same physical characteristics. A 3/32-inch-thick glass inner plate, for example, should not be used with a 3/16-inch-thick tempered cover plate. At the high temperatures existing during normal collector operation, and the even higher stagnation temperatures that result when the heat transfer fluid stops flowing, substantial internal pressures are exerted on the glazing. Thin plastic sheets or films, used as cover plates in certain applications, afford the advantages of light weight, relatively low cost, and increased fracture resistance. The plastic chosen should have proven long-term resistance to ultraviolet radiation breakdown. The durability of the plastic glazing material should also be evaluated in terms of resistance to elevated temperatures and thermal expansion properties.

Unlike glass, most plastics do not block the reverse transmission of long-wavelength radiation from the collector plate. Figure 31 shows the transmittance afforded by cover plate materials to radiation of various wavelengths. The radiation in the solar spectrum (0.4 microns to 3.0 microns) should be readily transmitted. The reradiation of long-wavelength infrared (3.0 to 15 microns) should be blocked in order to retain this heat within the collector. The ability of cover glazing to perform in this manner is important in applications where high temperature collection is required.

Absorber Plate Insulation

An absorber plate may reach temperatures in excess of 200°F regularly. To maximize energy collection from this heated plate, it must be well insulated.

	INSULATION		
	FIBERGLASS	URETHANE	EXTRUDED POLYSTYRENE FOAM
Heat Loss	Good	Excellent	Excellent
Moisture Resistance	Fair	Excellent	Excellent
Volatile Outgassing	Excellent	Poor	Fair
Temperature Resistance	Excellent	Fair	Poor
Desirability	Recommended	Not Recommended*	Not Recommended*

*Not recommended for high temperature application

TABLE 4/COMPARISON OF INSULATING MATERIAL PROPERTIES

The back of the collector is typically insulated with a 3 to 4-inch thick fiberglass blanket. The use of cellular plastics for this purpose requires special consideration. Under stagnant conditions, which occur when there is no flow of heat transfer fluid through the collector, the plate can reach temperatures approaching 400°F. Most foamed urethane insulations currently available undergo a permanent volumetric increase at approximately 250°F. Consequently, they can seriously distort if placed in direct contact with the absorber plate. Furthermore, foamed insulations are typically "blown" with chlorinated or fluorinated hydrocarbons which degrade at this temperature, producing hydrochloric and hydrofluoric acids. Both end products are corrosive to all metals.

A related problem is the outgassing of volatile elements from the insulation or from adhesives or wood products used in conjunction with the insulation. These volatile elements can condense on the inner surface of the glass and other portions of the collector. Polyurethane foam, which is "blown" with carbon dioxide, is not subject to the outgassing of such volatiles. It may offer an alternative to fiberglass insulation, when not subjected to stagnation temperatures.

Insulation materials may be combined to obtain the most beneficial aspects of each. For example, a layer of fiberglass between the collector and a foamed plastic insulation protects the latter from thermal damage. Since some foamed insulations have higher insulating values than fiberglass, this approach has merit. Care must be taken to be sure that temperature-sensitive insulation is adequately protected from the high temperatures which will occur at stagnation conditions.

Table 4 compares the important properties of three insulating materials: fiberglass, foamed urethane, and extruded polystyrene.

Freeze Protection and Heat Transfer Liquids

In climates where freezing is possible, protection must be provided to prevent damage to the collector. Two common ways of handling this problem are:

1) *The use of an anti-freeze solution*
2) *The draining of the fluid from the collector array when temperatures approach freezing.*

The basic heat transfer fluid used in liquid collectors is water. When other agents such as anti-freeze compounds are added, a solution pH of 7.0 or higher should be maintained. The addition of any substance to water, or the use of heat transfer oils, (some of which have been developed for solar systems), reduces the specific heat and requires the circulation of more fluid in order to remove a given amount of heat from the collector plate which may require the use of a larger pump. Due to the cost of anti-freeze agents, it is seldom economical to treat all of the system water—including that in the storage tank. Therefore, a heat exchanger between the fluid circulated through the collector and the storage tank fluid would be required. Any heat exchange operation reduces overall system efficiency.

When a draindown method of freeze protection is used, air is permitted to enter the system and displace the water in the collector loop. The water drains into the storage tank (or a separate holding tank) in a location not exposed to freezing temperatures. In some systems, an automatic air vent and an air solenoid valve are employed to permit the passage of air into and out of the system.

This type of freeze protection is shown in Figure 19 on page 14.

In atmospheric systems, which do not operate at an imposed pressure, it is often possible to allow the draining of the water in the collectors and the piping by the method shown in Figure 32. Because the return piping from the collector to the storage tank terminates above the water level in the tank, air can enter the piping through the vent in the tank lid. This breaks the suction at the high point of the system as air moves up the return piping. It is advisable to over-size the return piping slightly to facilitate air movement.

This method of freeze protection has been successfully employed in a number of collector installations. To insure proper system operation, the air path up the return piping must be unrestricted. Each installation should be carefully evaluated when this method is used. All the piping must be pitched to drain from the high point of the system, so that the water flows unimpeded into the storage tank. There should be no low points or pockets to trap water in portions of the piping exposed to freezing temperatures. This method of freeze protection is illustrated in the solar space heating section, Figures 24, 25, 28, 29 (pages 17, 18, 20, 21).

Some means for accommodating the expansion of fluid in all closed piping loops must be provided. All liquids expand when heated. Water, for example, expands about 4% per 100°F temperature rise.

In pressurized systems, such as domestic water heating systems, excess pressures due to expansion are normally provided for by using a pressure relief valve to drain excess water volume. A pressurized expansion tank or accumulator is appropriate for larger systems. In non-pressurized systems, expansion is accommodated by oversizing the storage tank and venting it to the atmosphere.

High Temperature Protection

Should fluid circulation through the absorber plate stop while the sun is shining, the solar collector can reach extremely high "stagnation temperatures." For a double-glass collector with a flat black surface, these temperatures reach 350°F to 400°F. Collectors with selective surfaces stagnate at even higher temperatures. The collector frame, piping connections and insulation must be able to withstand such temperatures.

Even when appropriate materials have been used, a system must be protected against the thermal shock produced when cold fluid is pumped into a collector that has reached stagnation temperature. This could be the case on initial system filling and start-up. This also might happen should a power failure prevent operation of the circulating pump. If power is not restored until after an hour or two of subsequent sunshine, the automatic restarting of the pump forces cool fluid through the collector which has reached stagnation temperatures. The resulting thermal shock can cause buckling of the absorber plate and breakage of the glass covers.

Protection against thermal shock can be provided in several ways. One method uses a temperature sensor on the back of the collector plate to actuate a cutout relay in the power supply to the circulating pump. When the collector plate reaches a preselected temperature, power to the pump is cut off preventing circulation of the collector fluid. An alternative means employs a timing device that prevents automatic restarting of the pump in the event of a power failure lasting more than a minute or two. A third method employs a temperature sensor to prevent pump operation when a preset temperature differential exists between the collector plate and the circulating fluid. The third method is generally more expensive than the two previous, especially for residential applications.

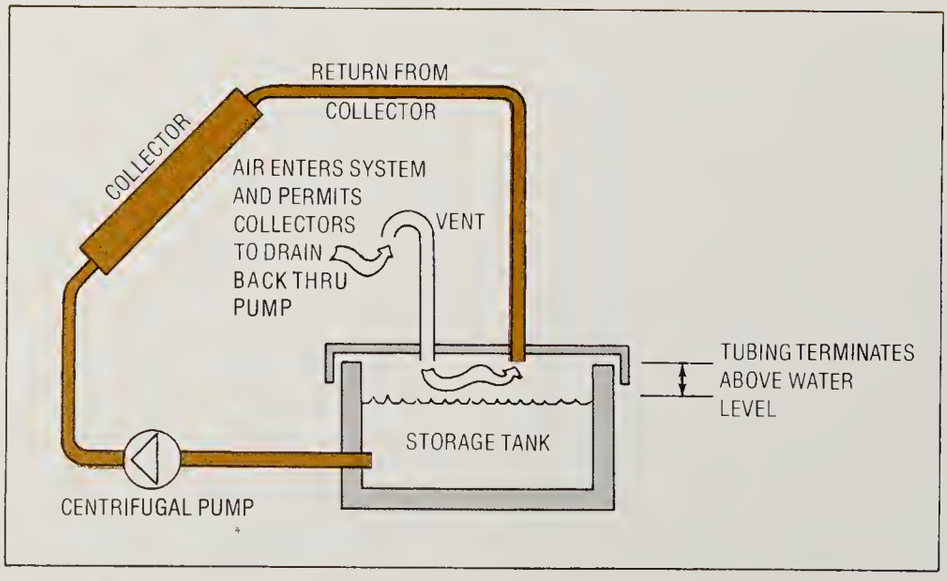


FIGURE 32/DRAINDOWN SYSTEM WITH AIR VENT

Circulating Pumps and Controls

Pumps ordinarily selected for residential and small commercial solar systems are close-coupled, in-line or base-mounted, centrifugal types with mechanical shaft seals and flexible drive couplings. Pumps used in potable water systems should be bronze bodied.

The designer should select a pump which has the proper combination of flow rate and lift characteristics for each application. In general, the pumps for solar collectors should be chosen to provide approximately one to three gallons of water per hour per square foot of collector surface in order to maintain a reasonable temperature differential across the collector plate. In open systems, pumps must have sufficient lifting capacity to raise water from the storage tank to the top of the collector circuit. For such systems which usually have a relatively high lifting requirement and low flow quantities, two small pumps connected in series are often the best alternative. In closed systems, the pumps are needed only to overcome friction losses through the piping.

The pump should not be oversized to the point where its typical operating characteristics are at a low efficiency. In most small solar systems, the pumps will not exceed 1/4 to 1/3 horsepower and may be as small as 1/6 to 1/20 horsepower in closed systems.

When centrifugal pumps are used, it is essential that they operate with a net positive suction head. This is most frequently accomplished by connecting the pump through the storage tank wall below the water level in the tank. Then, there is always a positive head of water in the tank above the pump. If the pump is not installed to operate with a net positive suction head, it will cavitate, causing damage to the pump.

The circulating pump in the collector loop is normally started and stopped by means of a differential temperature controller. This controller measures the collector temperature and the storage tank water temperature. When the collector temperature is higher than the tank water temperature, by a set amount, the controller actuates the circulation pump. When the collector water temperature

approaches the tank temperature, the pump is turned off. This differential thermostatic control assures that maximum heat energy is retained in the tank under all weather conditions.

Several manufacturers offer a variety of low-priced differential temperature controllers. Options are available to set a maximum storage tank temperature and to incorporate various freeze protection methods.

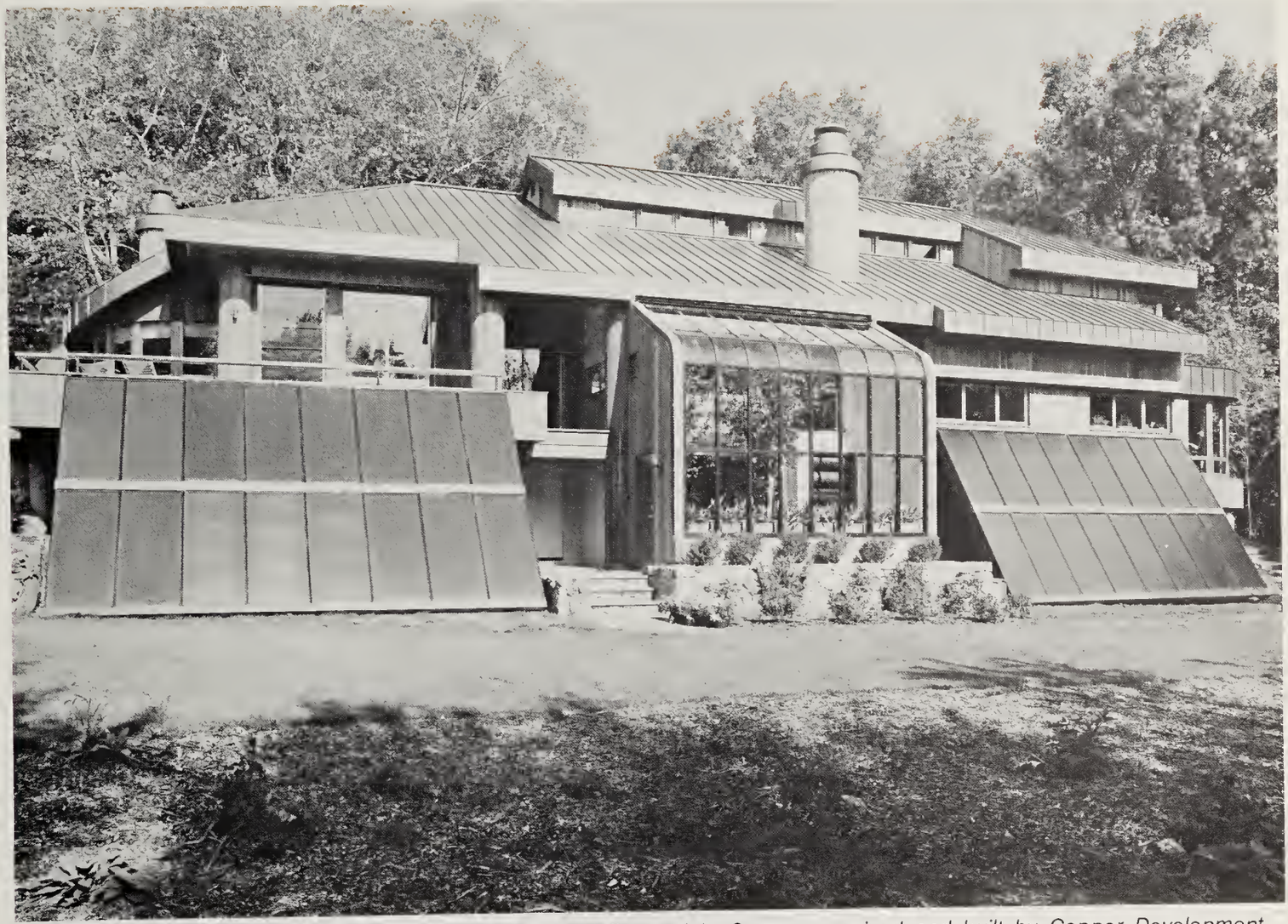
Collector Installation

Integration of collectors with the roof structure should be carefully considered. The construction should be watertight so that no leakage occurs into the collector or through the roof.

Collectors should be permitted to expand and contract freely. Temperatures will vary considerably in different sections of the collectors and the component parts will expand and contract at different rates. High temperature sealing (glazing) tapes must be used to maintain watertight seals. Silicone tapes and caulking compounds usually have excellent high temperature properties.

External sealants should be used which do not exhibit "thermal set" or a tendency to vulcanize when exposed to cycling temperatures. Thermal set can be a cause of leakage problems when contraction of the adjacent materials results from cooling. Maintenance of the collector should be considered when planning framing details. The collector should be easily removable for repairs when necessary.

When a particular collector is used, the manufacturer's recommended installation details should be followed without deviation. Neoprene glazing gaskets or commercial skylight framing systems are sometimes used. The manufacturer's recommendations for these products must be closely followed to assure a trouble-free installation. The return piping above the collector outlet should be pitched so that water is not trapped in the piping.



The "Sun/Tronic House" is a prototype solar home in Greenwich, Conn., conceived and built by Copper Development Association Inc. The active and passive solar energy systems provide more than 65% of the home's space heating and domestic hot water needs.

SECTION 7

DESIGN: SUN-CHART HAND CALCULATIONS

Sun-Chart is one method of simplified solar design. Other hand and computer methods are available for the design and sizing of solar systems. The decision to use a solar system is that of the designer or installer based on the portion of solar contribution desired. This contribution will in general range from 50-80% dependent on a number of factors which vary based on climate, building type, equipment and application. The ultimate decision of size and contribution of a solar system will normally be based on installed cost and payback period. The example used in Section 7 to carry through the Sun-Chart calculations is not intended to be representative of all climates, buildings, equipment, and applications. We are confident that the CDA Sun-Chart method along with the CDA Solar Energy Handbook will provide the solar community with a valuable tool for the development of solar energy.

Design Calculations

Solar design engineering normally entails extensive hand calculations or computer analysis to optimize system performance and cost. However, a simplified approach that permits rapid evaluation of heat loads and collector area has been developed. The CDA Sun-Chart Hand Calculations, for determining space and water heating loads, collector performance and recommended collector area, are described on the following pages.

This approach involves certain assumptions. In the majority of cases, these assumptions approximate normal conditions and generate results similar to those achieved by more extensive analysis. For most cases, results from these calculations have proved to be equal to, or slightly more conservative than, those achieved by computer analysis. The calculations are based on an average day for each month. In actual operation there will be overcast days when the solar collector may not operate, or very cold days when the requirements for heat will be higher. Generally, there is no reason to adjust the calculations unless an unusual situation exists. If the conditions on a particular application differ signficantly from the assumptions, it is advisable to have the calculations checked by a professional experienced in solar system design.

Each solar energy system must be engineered to meet the particular circumstance of its use. The Copper Development Association Inc. assumes no responsibility or liability of any kind in connection with the calculations or system designs set forth herein or their use by any person or organization and makes no representations or warranties of any kind.

Determining End-Use Heat Requirements

Water Heating. The amount of heat required to produce hot water depends on the number of gallons consumed, the inlet temperature of the cold water supply and the desired discharge temperature at the fixtures. Table 5 lists average monthly cold water supply temperatures, at the sources, for 14 cities in the United States. Deep wells, such as those in Miami, Albuquerque and Las Vegas, produce water at a relatively constant temperature that is related to locally prevailing deep earth temperatures. Water from shallow wells, lakes, and reservoirs varies in temperature throughout the year as the result of changing air temperatures.

		J	F	M	A	M	J	J	A	S	O	N	D
Albuquerque	W	62	62	62	62	62	62	62	62	62	62	62	62
Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
Fort Worth	L	46	49	57	70	75	81	79	83	81	72	56	46
Los Angeles	Ri	50	50	54	55	63	70	73	73	72	68	57	52
Las Vegas	L,W	57	64	68	71	77	85	87	86	78	70	65	57
Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
Nashville	Ri	46	46	53	63	66	69	71	75	75	71	58	53
New York	Re	36	35	36	39	47	54	58	60	61	57	48	45
Phoenix	Ri,Re,W	48	48	50	52	57	59	63	75	79	69	59	54
Salt Lake C.	W,C	35	37	38	41	43	47	53	52	48	43	38	37
Seattle	Ri	43	42	46	51	56	61	65	66	65	58	52	44
Washington	Ri	42	42	52	56	63	67	67	78	79	68	55	46

Source Data From Handbook of Air Conditioning System Design, p. 5-41 through 5-46; McGraw Hill Book Company, New York (1965). Abbreviations: C—Creek, L—Lake, Re—Reservoir, Ri—River, W—Well

TABLE 5/SOURCE AND MONTHLY TEMPERATURE IN °F AT THAT SOURCE FOR COLD WATER SUPPLY IN 14 CITIES

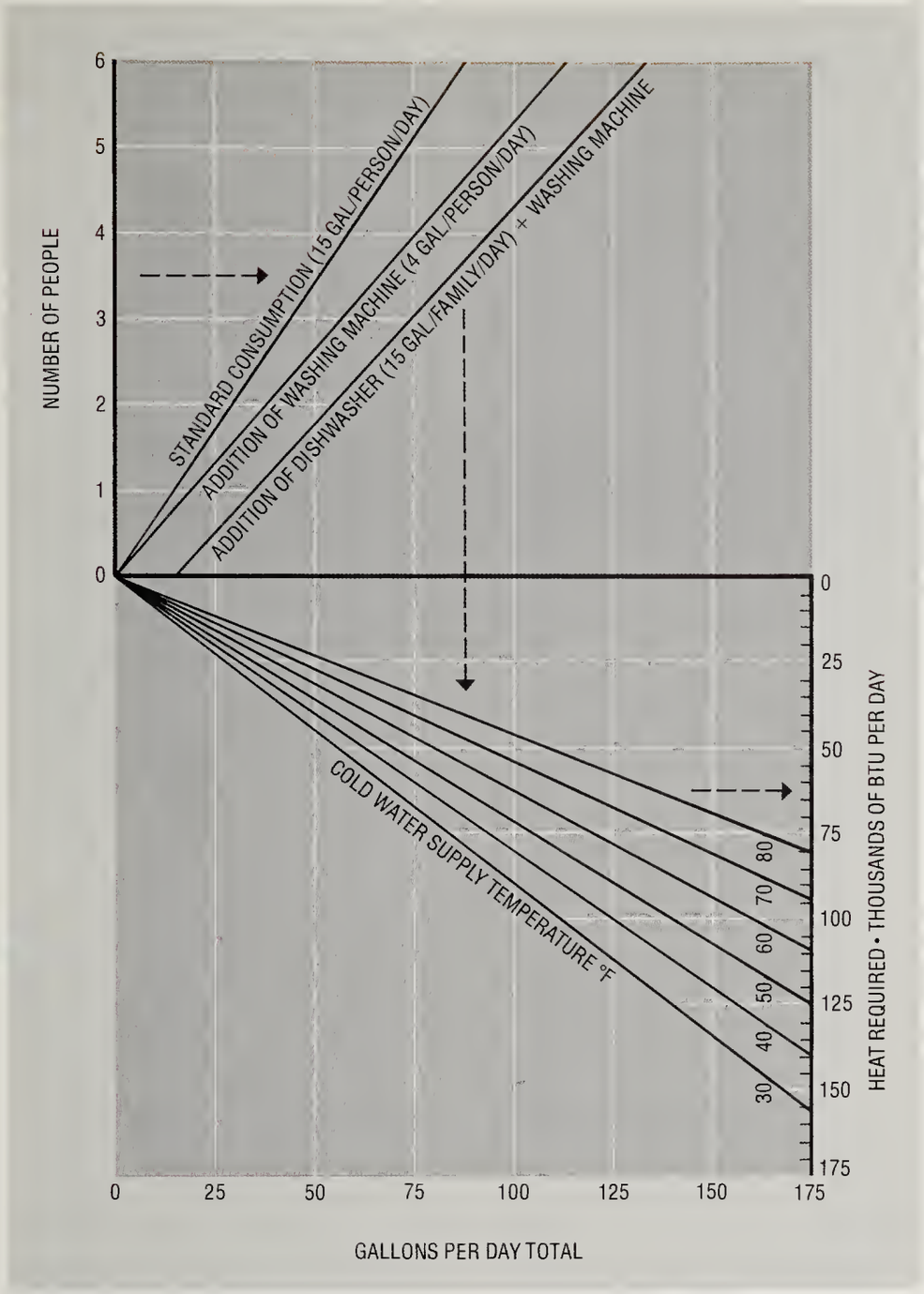

NUMBER OF PEOPLE
STANDARD CONSUMPTION (15 GAL/PERSON/DAY)
ADDITION OF WASHING MACHINE (4 GAL/PERSON/DAY)
ADDITION OF DISHWASHER (15 GAL/FAMILY/DAY) + WASHING MACHINE
COLD WATER SUPPLY TEMPERATURE °F
HEAT REQUIRED • THOUSANDS OF BTU PER DAY
GALLONS PER DAY TOTAL

FIGURE 33/ENERGY REQUIREMENTS FOR WATER HEATING/BASED ON 135°F D.H.W. SUPPLY TEMPERATURE

Example: Family of Four—
Nashville, Tennessee
High Consumption—
91 Gallons/Day

MONTH	COLD WATER TEMP.	HEAT REQUIREMENTS (BTU/DAY)
January	46	67,500
February	46	67,500
March	53	62,200
April	63	54,600
May	66	52,300
June	69	50,000
July	71	48,500
August	75	45,500
September	75	45,500
October	71	48,500
November	58	58,400
December	53	62,200

TABLE 6/DOMESTIC HOT WATER HEAT REQUIREMENTS

Contact local water suppliers for accurate information on average water temperatures.

Hot water consumption is the major factor influencing annual heat requirements. It requires 8.33 Btu to raise one gallon of water 1°F. If one gallon of water is heated from 35°F to 135°F., 833 Btu are required. This is equal to the energy consumed by a 60 watt light bulb burning for over four hours.

Authorities[1] differ in their estimates for hot water consumption, with a range of 50-120 gallons per day for a family of four, including appliance usage. Typically, a family of four has been found to consume 60-90 gallons of hot water daily. However, the total consumption of hot water depends primarily on the individual's habits and upon the characteristics of the plumbing fixtures or appliances used. Figure 33 has been developed to determine the heating requirement for different levels of hot water consumption based on either the number of people served, or the anticipated consumption in gallons per day.

Table 6 lists the heat required month-by-month to provide 135°F. hot water for a family of four living in Nashville, Tennessee, using a dishwasher and clothes washer. It may prove advantageous to plot a graph of the data obtained from Figure 33, as a means of spotting mathematical errors. Figure 34 is a graph constructed from the data in Table 6. The graph should curve smoothly. A sharp deviation in any month is a clue that an error exists.

Space Heating. When heating load calculations are made for a conventional heating system, the custom is to first determine the highest rate of heat loss anticipated for the building. The computed amount is then increased by some percentage ("safety factor") to cover unforeseen circumstances. The adjusted figure is used as the basis for equipment selection.

This practice often leads to the installation of oversized space heating systems that operate less efficiently and thus consume more energy. Heating equipment, particularly fossil-fuel equipment, usually delivers its design efficiency only at full capacity. Below this, efficiency falls off. Oil and gas furnaces are often designed to an efficiency of about 75 percent at full load. Yet, when installed in a building, these furnaces may attain a seasonal efficiency of only 50 percent or less.

In contrast, solar systems are designed to handle only a portion of the highest anticipated heat loss. The designer, therefore, is more concerned with the average heating load per day. A solar system sized to handle average rather than peak loads requires supplementary heat input on the coldest days. The system will operate near its full rated output much of the time. Therefore, its overall seasonal efficiency should be higher.

[1]a) Study of Energy Savings Options for Refrigerators & Water Heaters. Little (Arthur D.) Inc., Cambridge, Massachusetts, 1977.
b) Patterns of Energy Consumption in the United States, Office of Science & Technology, Executive Office of the President, 1972.

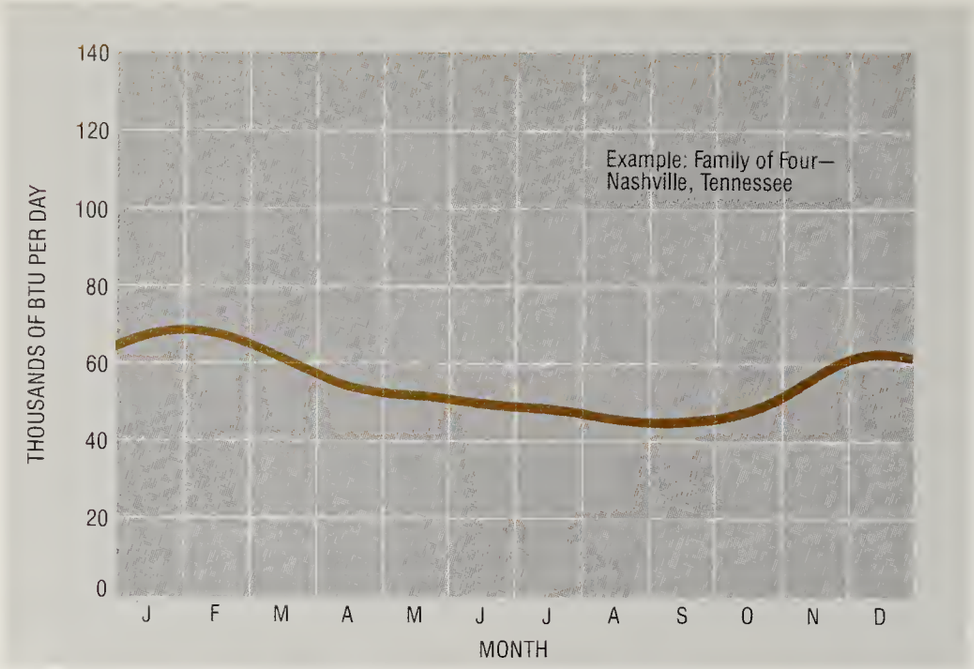


FIGURE 34/ WATER HEATING REQUIREMENTS GRAPH

Eligibility Criteria. The use of solar energy to provide space heating for a building should not be considered unless the building is energy conserving. To attempt to solar heat a building that is poorly designed from an energy standpoint is a waste of money. The investment for a solar energy system might be better spent on energy conservation features to reduce the building's heating requirements.

Many things contribute to the energy requirements of a building, including proportion, orientation (especially of large glass areas), exterior color, and the type of shell construction. Construction features which exert the greatest impact on energy conservation and are accounted for in design calculations are insulating glass or storm windows, control of the infiltration of outside air through joints between materials, and the type and amount of wall and roof insulation.

Extreme care should be exercised in selecting the wall and roof insulation materials. Cellulosic fiber insulating materials containing ammonium sulfate as a fire retardant should not be used in contact with copper or other metals. The ammonium sulfate may leach from the insulation and cause serious corrosion damage to piping, electrical and similar metal components.

Heat loss, measured in Btu per square foot per degree day, is a major criterion in judging whether or not a building is suited for solar space heating. In general, a solar system should be considered for a residence only when the space heating demand has been limited to approximately 8 Btu per square foot per degree day or less.

To apply this criterion to a building which is being considered for solar heating, calculate the building's energy requirements under peak design conditions. This calculation determines the heat required when the outdoor temperature is at the design point, and is normally done by the designer for the purpose of sizing conventional heating equipment. The design point temperature is based on hourly average temperatures for each hour of a total year. The average hourly temperatures will be above the design point temperature 97½ percent of the year. In Nashville, Tennessee, for example, the heating design point temperature is 17°F. Heat loss calculation methods are well documented in existing texts and are not repeated here.

To determine the average heating requirements, instead of the peak heating requirements, the concept of degree days is used. A degree day is a standard used to measure the heating season's severity. The number of degree days in a calendar day is determined by subtracting the day's mean temperature from 65°F. If the mean temperature on a given day is 50°F, subtracting 50°F. from 65°F. yields 15 degree days for that calendar day. By adding the number of degree days in each day, the average monthly conditions are identified. The average monthly and yearly degree days for cities in the United States and Canada are listed in Appendix A.

Sample Calculations. An example may help to illustrate how the heat loss is calculated to determine solar system feasibility.[2] Consider a home in Nashville, Tennessee, which loses 30,000 Btu per hour, when the outdoor temperature is 17°F. If this temperature exists for a 24-hour period, the building heating demand is 30,000 x 24 = 720,000 Btu. Since the design point temperature is 17°F., (48 degree days per day), the house requires a net heat input of 15,000 Btu per degree day as shown below:

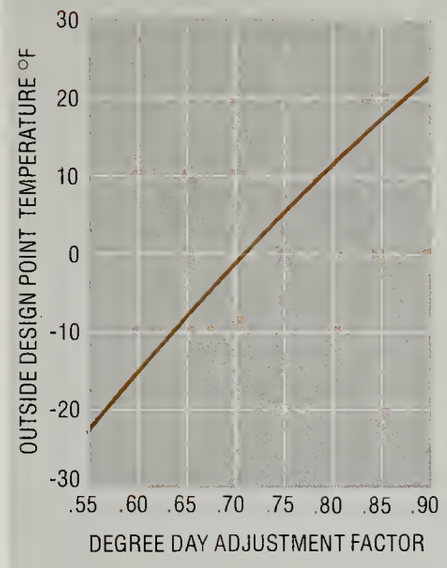
$$\frac{\text{30,000 Btu/hr. x 24 hours}}{\text{(65°F Degree Day Base—17°F. Design Point Temperature)}} = \text{15,000 Btu/DD}$$

If the home's floor area is 2,000 square feet, the required heat input is 7.5 Btu per square foot per degree day. Since this is less than the criterion of 8 Btu per square foot per degree day, the house is a good candidate for solar space heating.

In actual practice, most homes experience an annual heating requirement which is somewhat less than that obtained by the above calculation method. The reason for this difference is that the design heating load does not account for heat gain from other sources such as people, lights, and cooking. Also, the house itself acts as a solar collector to some extent. The exterior surfaces, particularly windows, absorb or admit some of the incident solar energy. In the heating season, these heat gains lower the building heating demand. Since they are not always present, they are not included in the peak heat load calculation. They are, however, accounted for when the modified degree day procedure is used to calculate heating requirements on average days. This is done by using a "Degree Day Adjustment Factor".

The adjustment factor is used to calculate average monthly requirements from the peak design load information. For example, after determining the number of Btu per square foot per degree day, the building heating requirement can be calculated by obtaining the figure for monthly degree days from the Appendix. Dividing this figure by the number of days in the month gives the average degree days per day for that month. The building's average heating requirement per day for each month is then determined by multiplying the average number of degree days by the Btu per square foot per degree day, the total floor area in square feet and the adjustment factor. The adjustment factor is obtained from Figure 35, which compares the outside design temperature with the degree day adjustment factor. In this example, since the outside design temperature in Nashville is 17°F., the adjustment factor is 0.86.

[2]The method outlined is based on the "Modified Degree Day Procedure." "ASHRAE Handbook and Product Directory, 1976 Systems", American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1976.



The outside design point temperature is based on hourly average temperatures for each hour of a total year. The average hourly temperatures will be above the design point temperature 97½ percent of the year.

FIGURE 35/HEAT LOSS VS. DEGREE DAYS INTERIM ADJUSTMENT FACTOR[1]

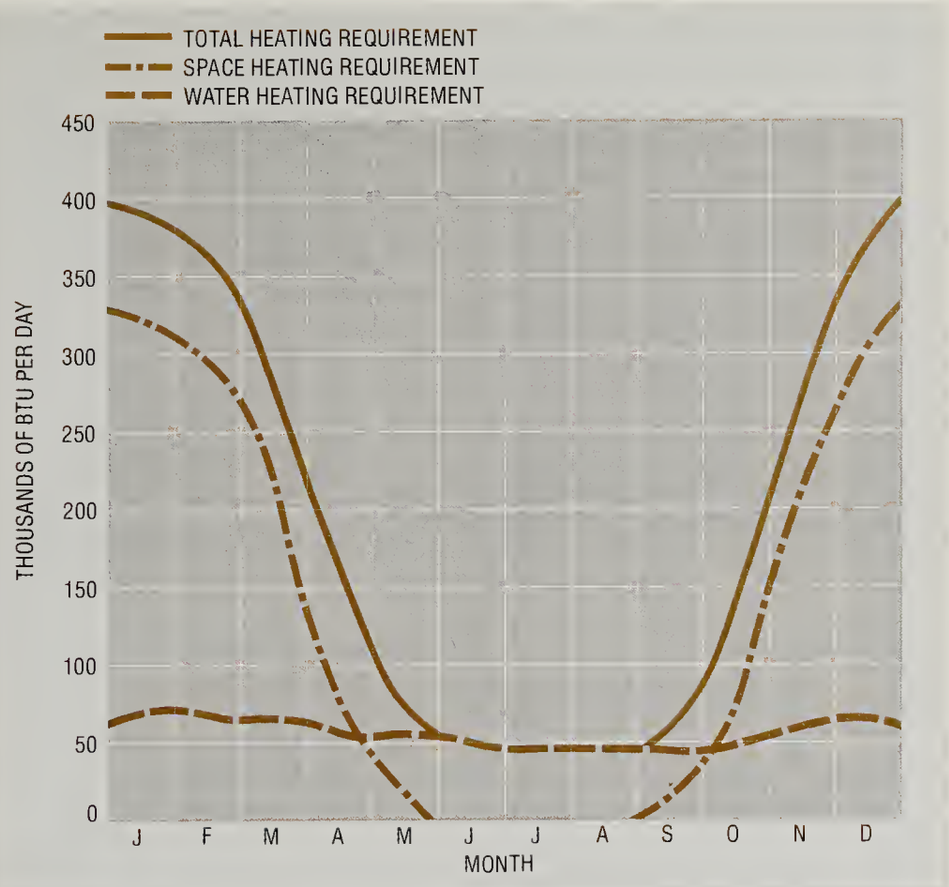


FIGURE 36/TOTAL HEATING REQUIREMENTS GRAPH

For January, the calculation is as follows:

January—NASHVILLE, TENN.

$$\frac{778 \text{ Degree Days/Month}}{31 \text{ Days/Month}} = 25 \text{ Degree Days/Day}$$

Average Heat Requirement (Btu/Day) = 25 DD/Day x 7.5 Btu/Sq. Ft./DD x 2000 Sq. Ft. x 0.86 Adjustment Factor = 322,500 Btu/Day

This calculation is repeated for each month of the heating season, and the results should be tabulated as in Table 7.

These space heating monthly figures can be added to the monthly figures for domestic water heating in Table 6 to obtain total heating requirement. The three curves plotted on the graph in Figure 36 then represent hot water, space heating, and total heating requirements.

Heat Required Vs. Energy Consumed. If the monthly heating requirements are supplied by a fossil fueled furnace or boiler, the energy consumed is greater than the total heating requirement because of the inefficiency of combustion.

For example, if the home in Nashville, which requires 30,000 Btu/hr. for space heating at peak design conditions, has a furnace rated at 36,000 Btu/hr., the furnace is oversized by 20 percent. As shown in Figure 37 this means that the seasonal efficiency of the furnace is about 48 percent.

In January, then, when 322,500 Btu/day are required, it will take 671,875 Btu/day of some type of fossil fuel to supply this load. (322,500 Btu/day ÷ 0.48) If fuel oil is used, which has a rated value of 140,000 Btu/gallon, 4.8 gallons are consumed per day to supply the average load. If a solar system could deliver 50 percent (161,250 Btu) of the average daily space heating requirement in January, it would supply the equivalent of 335,938 Btu of fuel oil energy.

Example: Nashville, Tennesse

Month	(BTU/Day)
January	322,500
February	296,700
March	213,000
April	81,270
May	16,650
June	0
July	0
August	0
September	12,900
October	65,750
November	212,850
December	304,600

TABLE 7/SPACE HEATING REQUIREMENTS

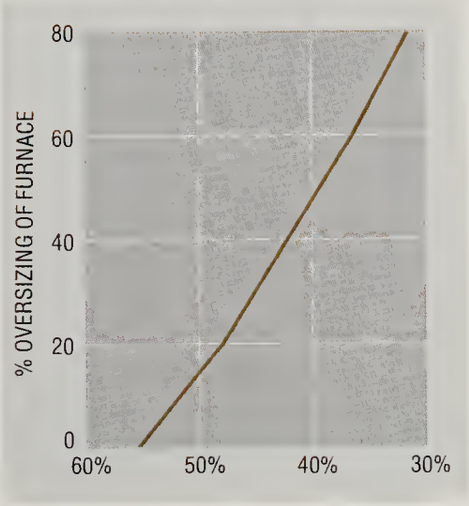


FIGURE 37/SEASONAL EFFICIENCY OF A FURNACE WITH A RATED FULL LOAD EFFICIENCY OF 75%*

*"ASHRAE Handbook & Product Directory, 1976 Systems," ASHRAE, Inc., New York, N.Y., 1976.

Computing Collector Output

The CDA Sun-Chart Hand Calculations is an easy method to use to calculate the solar energy obtainable from collectors in residential space heating and domestic water heating applications. Normally, solar heat calculations use sophisticated computer analysis. Such analysis is required for large-scale solar energy applications, particularly those involving cooling, where it is important to determine the heat that can be collected on an hour-by-hour basis. For small-scale systems, however, this simplified method provides results which closely approximate those achieved by computer analysis. Heat pump systems in which the solar system and the heat pump are not directly linked, such as that shown in Figure 28, can also be analyzed reasonably well by this procedure.[3] More sophisticated analysis methods are required for applications which use a heat pump to extract energy from a solar storage container.

The simplification is accomplished by making the following assumptions about the solar system characteristics:

(1) The collector orientation is within 15 degrees of due South. For applications which differ significantly from this assumption, adjustments can be made by using the orientation graph in Figure 13 on p. 9 of this manual.
(2) Collectors with circulating liquids are used to carry collected energy to storage or load.
(3) Water storage capacity ranges from 1½ to 2 gallons per square foot of collector array.

The CDA Sun-Chart Hand Calculations for determining collector heat production are best explained by referring to a tabulation chart, Figure 38, devised to guide and facilitate the computation procedures. The designer begins by entering in the first five columns (A through E) available data concerning the application. He then performs six mathematical operations using these basic data and enters the results in columns F through L. A final multiplication yields data for the "Result" column; i.e., the average daily heat produced during each of the 12 months by one square foot of collector at a given tilt angle, operating at a specific temperature and installed in a particular locality. All of the computations are basic mathematical functions easily performed on a pocket calculator, or by hand.

In order to fully appreciate the logic process shown in the design chart, the user should understand the significance of each column. The following explanatory notes may be helpful.

JOB: COLLECTOR TYPE:
LOCATION: COLLECTOR TILT.
LATITUDE: APPLICATION:

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG S LIT	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG S LIT	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G - COLUMN C °F	J = $\frac{B}{A}$ x2H	K = $\frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU/SQ FT /DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

FIGURE 38/ THE CDA SUN-CHART WORKSHEET

Data Input

(Columns A Through E)

Column A is the collector heat gain factor. Each type of collector has a characteristic ability to absorb solar energy. This ability is determined, in part, by the quality of the glass and the absorptivity of the blackened absorber plate surface. Table 8 p. 33 lists the collector heat gain factors for four representative types of copper flat plate solar collectors.

For specific flat plate solar collectors, this factor is determined from a performance graph as shown in Figure 39.[4] A graph for any collector can be obtained from the manufacturer. The collector heat gain factor is the point at which the sloped line intersects the vertical axis of the graph.

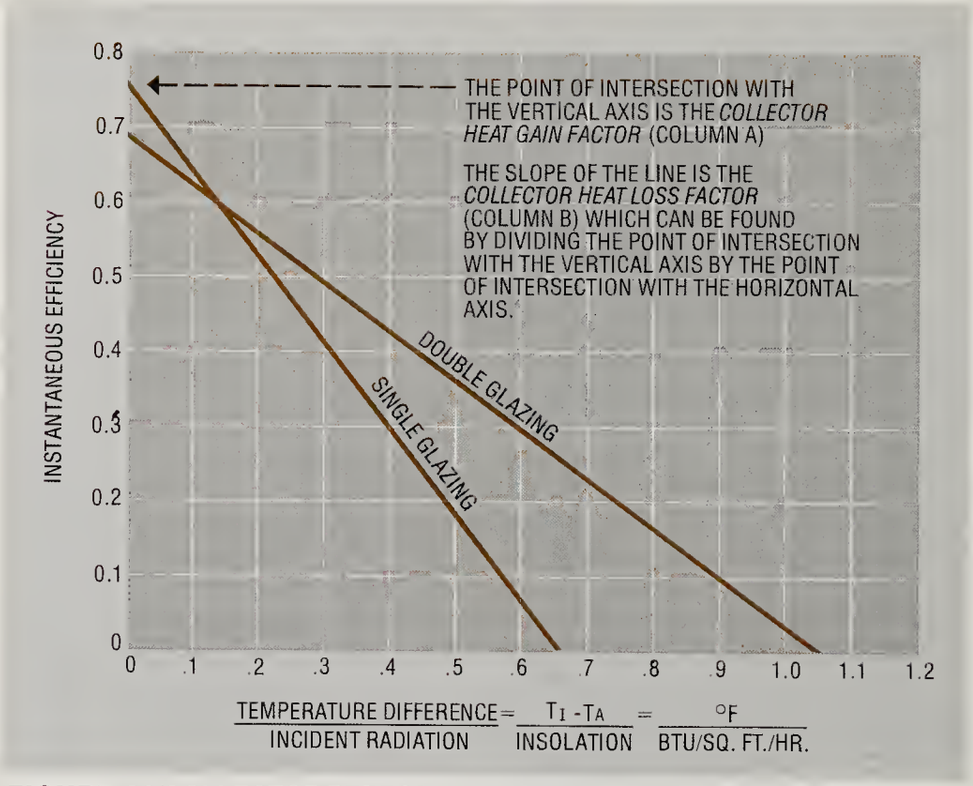

INSTANTANEOUS EFFICIENCY
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2
THE POINT OF INTERSECTION WITH THE VERTICAL AXIS IS THE COLLECTOR HEAT GAIN FACTOR (COLUMN A)
THE SLOPE OF THE LINE IS THE COLLECTOR HEAT LOSS FACTOR (COLUMN B) WHICH CAN BE FOUND BY DIVIDING THE POINT OF INTERSECTION WITH THE VERTICAL AXIS BY THE POINT OF INTERSECTION WITH THE HORIZONTAL AXIS.
DOUBLE GLAZING
SINGLE GLAZING
TEMPERATURE DIFFERENCE / INCIDENT RADIATION = TI - TA / INSOLATION = °F / BTU/SQ. FT./HR.

FIGURE 39/COLLECTOR PERFORMANCE CHARACTERISTICS/TYPICAL VALUES—COPPER FLAT PLATE COLLECTORS

[3]For greater accuracy, use the bin data procedure, as shown in the "ASHRAE Handbook and Product Directory, 1976 Systems", Chapter 43, ASHRAE, Inc., New York, N.Y., 1976.

[4]The graph should be the results of a test of collector production conducted in accordance with ASHRAE Standard 93-77 (ANSI B198.1-1977) "Methods of Testing to Determine the Thermal Performance of Solar Collectors", ASHRAE, Inc., New York, N.Y., 1977 or a similar recognized standard.

Column B is the collector heat loss factor. When collectors absorb solar energy, they tend to yield back the heat gained to the surrounding air. To achieve good operating efficiency, this heat loss should be minimized by insulation and other techniques. Table 8 lists the collector heat loss factors for four types of flat plate solar collectors. For other types, this value can be obtained from manufacturers' data as shown in Figure 39. The collector heat loss factor is equal to the slope of the line. The slope value is determined by dividing the point at which the sloping line intersects the vertical axis by the point at which it intersects the horizontal axis. Both collector heat gain factors and heat loss factors are a function of each particular collector and remain the same in each of the 12 months.

Column C is the average air temperature. Ideally, this temperature should be the daytime average air temperature, but this data is often not available. Average full day air temperature for each month is usually available from a local weather station. The daytime average air temperature can be found by adjusting the average full day temperature. This is done by adding a value equal to 1/3 of the daily temperature range (usually 15°-20°F.) to the average full day temperature.

Column D is the horizontal solar energy. This is the amount of solar energy received by a horizontal surface on an average day in each month. The information is given in the insolation tables, Appendix B, expressed in Btu per square foot per day. Find the city nearest the location for which the calculation is being done.

Column E is the collector tilt factor. A surface inclined toward the sun receives an amount of energy in each month of the year that differs from the radiation incident on a horizontal surface. The collector tilt factor is a multiplier used to adjust the incident horizontal solar energy to obtain the amount received by a tilted collector. Appendix C gives the collector tilt factors based on collector tilt angles at various latitudes for each month of the year.[5]

To determine the proper tilt factor, determine the "% Diffuse Radiation" from the same table and location from which the "Horizontal Solar Energy" was determined. Use this "% Diffuse" figure to select the proper tilt factor table.

For example, in January, Nashville, Tennessee has a % diffuse factor of 65%. The latitude of Nashville is 36° North. If a collector tilt (angle to horizontal) of 51° (latitude + 15°) is desired, we must interpolate between both the positions of latitude and the tables for % diffuse. First interpolate for latitude on each of the two applicable % diffuse charts (60% and 80%). On the 60% chart, we interpolate between the January factor for a collector tilt of latitude + 15°, for 32° latitude (1.37) and for 40° latitude (1.60). Since the latitude of the site (36°) is midway between, the result is 1.485 (say 1.49). Similarly, for the 80% chart, the result is 1.28. Since the % diffuse for Nashville in January is 65%, an interpolation between 1.49 and 1.28 yields a tilt factor of 1.4375 (say 1.44). Therefore, 1.44 should be inserted in Column E for January.

[5]These collector tilt factors were generated by the basic procedure described in the publication, "Applications of Solar Energy for Heating and Cooling of Buildings", ASHRAE, INC., New York, N.Y., 1977. Minor modifications to this procedure were made for the purpose of this calculation.

Computation Section

(Columns F Through L)

Column F is obtained by multiplying the quantities from Columns D and E. The result is the amount of solar energy incident on a tilted surface. This is not the amount actually collected, but the total amount that reached the outer glazing of the collector.

Column G is the assumed collector inlet temperature. In reality, the inlet temperature which the collector experiences varies throughout the day, depending upon the heating load and the available solar energy. These values, which are obtained from Table 9, were developed for these calculations only, and are different for each month.

Column H is the temperature difference between the collector inlet and the ambient air. It is obtained by subtracting Column C from Column G.

Column J is obtained by dividing Column B by Column A and multiplying the result by 2 times the quantity from Column H. This yields the "critical intensity" for a specific collector in a given location operating at a specific temperature. Critical intensity is indicative of the length of the time period in each day during which the collector produces energy. It is not necessary to know the actual period of collector operation.

Column K is obtained by dividing the result from Column J by the quantity from Column F. This is a continuation of the previous step, involving the critical intensity and the period of collector operation.

Column L is obtained by using Figure 40, Collectable Energy Graph, and the quantity obtained in Column K. The result is achieved by finding the point on the K axis which corresponds to the answer from the previous step, and moving to intersect the curved line which is a turning point from which the line is continued to intersect the L axis.

COLLECTOR DESCRIPTION	A Heat Gain Factor	B Heat Loss Factor
1 Cover Plate Copper Absorber with Flat Black Surface	.78	1.35
2 Cover Plates Copper Absorber with Flat Black Surface	.72	.90
1 Cover Plate Copper Absorber Selective Surface	.76	.85
2 Cover Plates Copper Absorber Selective Surface	.70	.65

TABLE 8/COLLECTOR DESIGN SAMPLE VALUES

	Combined Space Heating and Domestic Water Heating	Domestic Water Heating Only (Add to Cold Water Supply Temperature)
January	100°	CWS + 20°
February	115°	CWS + 35°
March	140°	CWS + 60°
April	155°	CWS + 75°
May	165°	CWS + 85°
June	175°	CWS + 95°
July	180°	CWS +100°
August	180°	CWS +100°
September	175°	CWS + 95°
October	150°	CWS + 70°
November	130°	CWS + 50°
December	105°	CWS + 30°

TABLE 9/COLLECTOR INLET TEMPERATURES (COLUMN G)

Output Data

Result Column. The final result is the amount of heat collected in Btu per square foot per day. It is obtained by multiplying the values from Columns F and L. This is the energy collected on an average day in a particular month. No further adjustments are required.

Collector Sizing. Once the rate of energy output from the collector has been determined, the designer can proceed to find the collector area needed for a specific application. As previously indicated, it is normally not economically practicable to size solar systems to handle 100 percent of the heating requirements. Generally, a domestic water heating system is sized to supply 70-80 percent of annual heating requirements. In a space heating system or combined space and water heating system, sizing is aimed at using

solar energy for 60-70 percent of the annual heating requirements. As a rule, the designer achieves these percentages of overall annual load when the system is sized to supply 100% of the heat required during May for water heating or during March for space heating.

To make a preliminary estimate of collector area for a domestic water heating system, the designer refers back to the month-by-month water heating requirements tabulated and plotted in Table 6 and Figure 34. The heating requirement for May (52,300 Btu) is divided by the collector output rate calculated for that month. The collector area determined will, in theory, provide 100 percent of the May heat requirement.

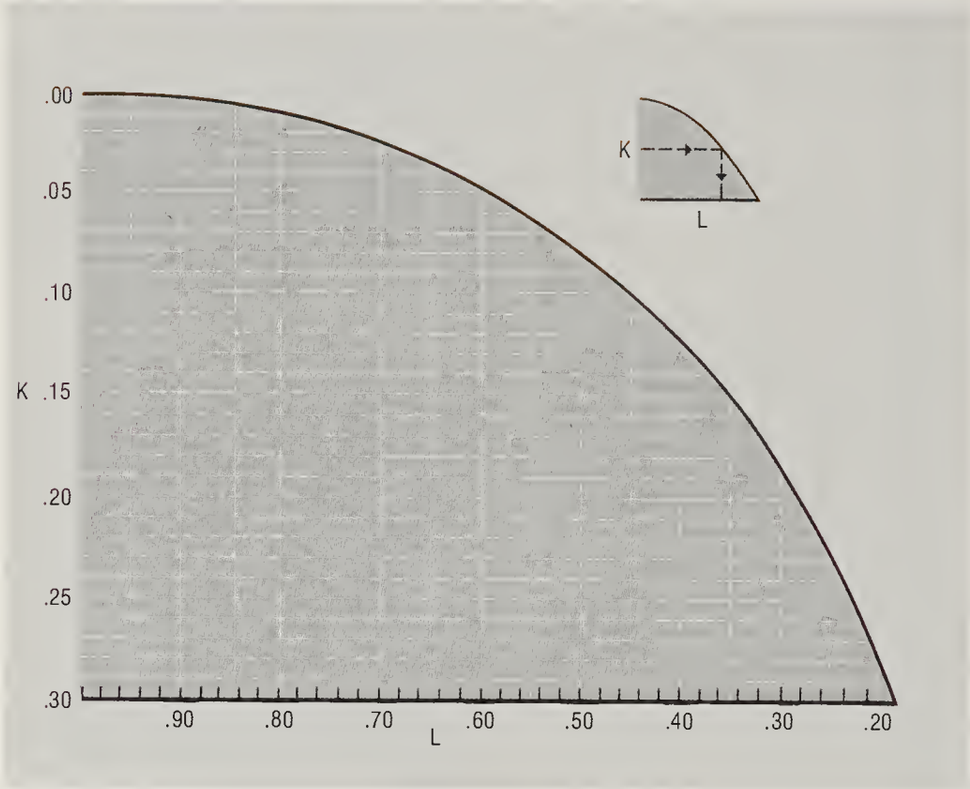


FIGURE 40/COLLECTABLE ENERGY GRAPH *(SEE "Column L," p. 33)*

	[1] TOTAL SPACE & DWH HEAT REQUIRED (BTU/DAY)	[2] USABLE COLLECTOR PRODUCTION FOR VARIOUS COLLECTOR AREAS (BTU/DAY)		
		500 SQ.FT.	400 SQ.FT.	350 SQ.FT.
January	390,000	181,500	145,200	127,050
February	364,200	252,500	202,000	176,750
March	275,200	272,000	217,600	190,400
April	135,870	(135,870) [3]	(135,870)	(135,870)
May	68,950	(68,950)	(68,950)	(68,950)
June	50,000	(50,000)	(50,000)	(50,000)
July	48,500	(48,500)	(48,500)	(48,500)
August	45,500	(45,500)	(45,500)	(45,500)
September	58,400	(58,400)	(58,400)	(58,400)
October	114,250	(114,250)	(114,250)	(114,250)
November	271,250	(271,250)	223,200	195,300
December	366,800	217,000	173,600	151,900
	2,188,920	1,715,720	1,483,070	1,362,870
Percent of Annual Load Supplied by Solar		78%	68%	62%

[1] Sum of Tables 6 and 7.
[2] Products of energy collected (BTU/sq. ft./day) x collector area.
[3] Numbers in parentheses are the *useful* solar energy, when the calculated production is greater than the requirement.

TABLE 10/ANNUAL HEAT REQUIREMENTS AND CALCULATED SOLAR COLLECTOR PRODUCTION

The collector area obtained should be considered preliminary. Next, the designer determines the percentage of the annual hot water heating requirement actually met by solar energy. For this test, the estimated collector area is multiplied, in turn, by the collector heat production figure for each of the 11 remaining months. Add the heat produced each month by the collector area selected and compare the total with the 12 months' sum of heating requirements. (For each month in which the solar collector produces more than 100 percent of the heating requirement, only that portion actually used is included in the collector production total.) The result is that fraction of the total annual hot water heating requirement met by solar energy. If the percent of the load handled by the solar array is too low or too high, adjustments are made to the collector area to bring it into the appropriate percentage range.

A graphic check is often helpful, and can be done by superimposing the values of collector production on the domestic water heating requirements curve. The juxtaposed curves provide a clear comparison of water heating requirement versus solar energy available for each month of the year. A similar curve, representing space and water heating, is shown in Figure 41.

Sample Calculation

The following example illustrates how the computation procedures are applied to a combined space and domestic hot water heating application.

Step I. List parameters of application.
Location: Nashville, Tennessee
Latitude: 36° North
Collector Type: Double Glazed with Selective Surface
Collector Tilt: 51°
Combined Space and Water Heating Heat Requirements: Shown in Table 10

Step 2. Work through the design chart to determine month-by-month solar heat output per square foot of collector surface. (Results are shown in Figure 42)

Step 3. In the completed chart (Figure 42) find the amount of heat available from the collector during March. This is 544 Btu/Sq. Ft./Day.

Step 4. Find the combined space and water heating requirement for the month of March. This is 275,200 Btu/day. (Table 10)

Step 5. Make a preliminary estimate of required collector area by dividing 544 into 275,200. The answer is about 500 square feet.

Step 6. Make a numerical check of estimated collector area by dividing the total solar heat collected (1,715,720 Btu, from Table 10) by the annual heat requirement (2,188,920 Btu, from Table 10). (In any month, only that portion of the collectable energy which can be applied to the load is considered. Therefore, for example, in May when only 68,950 Btu/day are required, only this portion of the available solar heat is applied to the load.) The estimated collector area of 500 square feet would supply 78% of the annual load, as shown in Table 10. Since this is higher than desired, an adjusted collector area of 400 square feet is tried. This yields a result of 68% of the total load supplied by solar energy. This is consistent with the recommended 60-70 percent. A third trial is made, using 350 square feet as a collector area. This area provides about 62% of the annual heating requirement. The collector area which should be selected for this job would be between 350-400 square feet.

Step 7. A graphic check of the calculated results is made (Figure 41). The shaded area is the useful solar heat produced by 350 square feet of collector area.

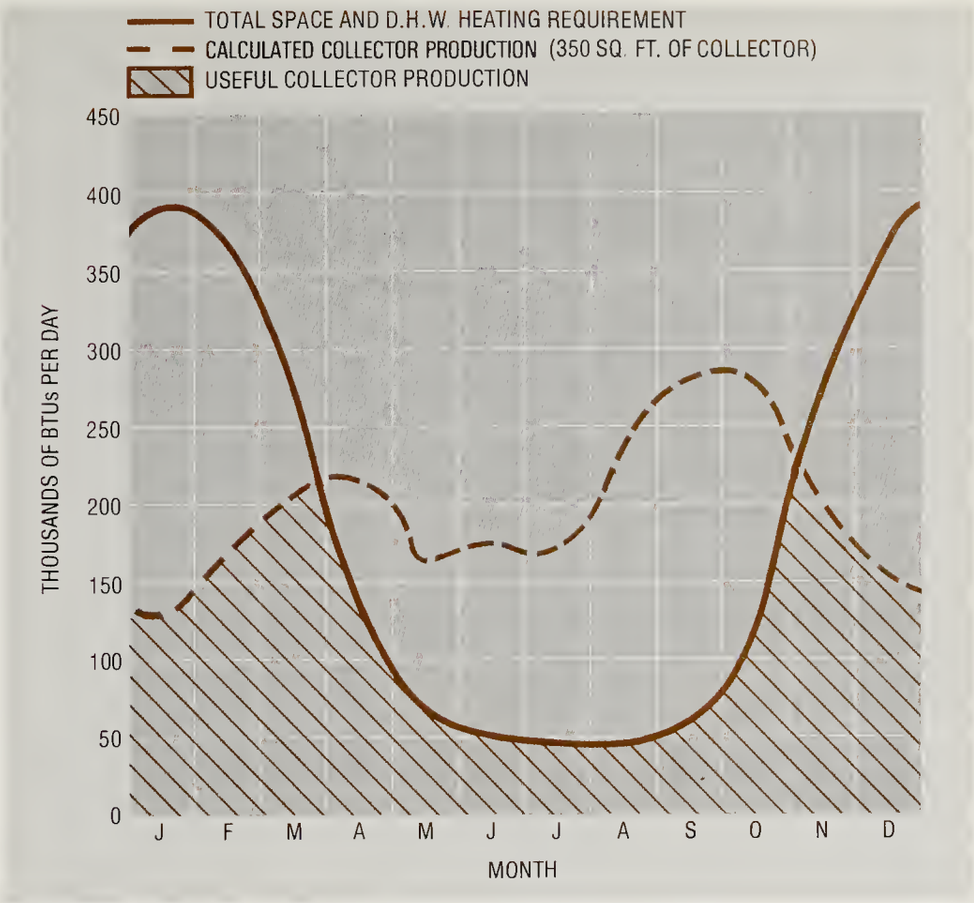


FIGURE 41/HEAT LOAD VS. SOLAR PRODUCTION GRAPH/ EXAMPLE: NASHVILLE, TENN. SPACE AND WATER HEATING

JOB: CDA Solar Home
LOCATION: Nashville, Tennessee
LATITUDE: 36° North

COLLECTOR TYPE: Double Glazed Selective Surface
COLLECTOR TILT: 51° (Latitude + 15°)
APPLICATION: Space and Water Heating

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT.	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT.	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G − COLUMN C °F	J = $\frac{B}{A}$ x2H	K = $\frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU SQ. FT. DAY
JANUARY	.70	.65	46	601	1.44	865	100	54	100	.12	.42	363
FEBRUARY	.70	.65	48	882	1.30	1147	115	67	124	.11	.44	505
MARCH	.70	.65	57	1188	1.09	1295	140	83	154	12	.42	544
APRIL	.70	.65	67	1638	.88	1441	155	88	163	.11	.44	634
MAY	.70	.65	76	1911	.63	1204	165	89	165	.14	.37	445
JUNE	.70	.65	84	2081	.61	1269	175	91	169	.13	.39	495
JULY	.70	.65	87	2033	.62	1260	180	93	173	.14	.37	466
AUGUST	.70	.65	86	1845	.89	1642	180	94	175	.11	.44	722
SEPTEMBER	.70	.65	81	1561	1.10	1717	175	94	175	.10	.46	790
OCTOBER	.70	.65	69	1199	1.42	1703	150	81	150	.09	.48	817
NOVEMBER	.70	.65	55	808	1.57	1269	130	75	139	.11	.44	558
DECEMBER	.70	.65	47	605	1.63	986	105	58	108	.11	.44	434

FIGURE 42/COMPUTED COLLECTOR PRODUCTION/EXAMPLE: NASHVILLE, TENN. SPACE AND WATER HEATING

CDA SUN-CHART CALCULATION WORKSHEET

JOB:
LOCATION:
LATITUDE:

COLLECTOR TYPE:
COLLECTOR TILT:
APPLICATION:

	A	B	C	D	E	F	G	H	J	K	L	RESULT
	COLLECTOR HEAT GAIN FACTOR (TABLE 8) OR MFG'S LIT.	COLLECTOR HEAT LOSS FACTOR (TABLE 8) OR MFG'S LIT.	AVERAGE DAYTIME AIR TEMPERATURE °F	HORIZONTAL SOLAR ENERGY (FROM TABLES) APPENDIX B	COLLECTOR TILT FACTOR (FROM TABLE) APPENDIX C	INCIDENT ENERGY F = D x E	COLLECTOR INLET TEMPERATURE (TABLE 9) °F	H = COLUMN G − COLUMN C F	J = $\frac{B}{A}$ x2H	K = $\frac{J}{F}$	'L' IS FOUND FROM FIGURE 40 USING 'K'	TOTAL ENERGY COLLECTED = F x L BTU/SQ. FT. DAY
JANUARY												
FEBRUARY												
MARCH												
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER												

Worksheets are available upon request from Copper Development Assn. Inc.

Appendix A

TABLE 11/AVERAGE MONTHLY AND YEARLY DEGREE DAYS FOR CITIES IN THE UNITED STATES AND CANADA[a,b,c] (BASE 65°F)

HOW DEGREE DAYS ARE MEASURED:

A degree day is a standard measure used by heating engineers to measure the heating season's coldness. The number of degree days in a calendar day is determined by subtracting the day's mean temperature from 65. If the high on a given day was 60 and the low was 40 the mean temperature that day would be 50. Subtracted from 65, this would give 15 degree days for that calendar day.

UNITED STATES

State	Station	Avg. Winter Temp. °F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ala.	Birmingham ..... A	54.2	0	0	6	93	363	555	592	462	363	108	9	0	2551
	Huntsville ..... A	51.3	0	0	12	127	426	663	694	557	434	138	19	0	3070
	Mobile ..... A	59.9	0	0	0	22	213	357	415	300	211	42	0	0	1560
	Montgomery..... A	55.4	0	0	0	68	330	527	543	417	316	90	0	0	2291
Alaska	Anchorage ..... A	23.0	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864
	Fairbanks ..... A	6.7	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279
	Juneau ..... A	32.1	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9075
	Nome..... A	13.1	481	496	693	1094	1455	1820	1879	1666	1770	1314	930	573	14171
Ariz.	Flagstaff ..... A	35.6	46	68	201	558	867	1073	1169	991	911	651	437	180	7152
	Phoenix..... A	58.5	0	0	0	22	234	415	474	328	217	75	0	0	1765
	Tucson..... A	58.1	0	0	0	25	231	406	471	344	242	75	6	0	1800
	Winslow..... A	43.0	0	0	6	245	711	1008	1054	770	601	291	96	0	4782
	Yuma..... A	64.2	0	0	0	0	108	264	307	190	90	15	0	0	974
Ark.	Fort Smith..... A	50.3	0	0	12	127	450	704	781	596	456	144	22	0	3292
	Little Rock..... A	50.5	0	0	9	127	465	716	756	577	434	126	9	0	3219
	Texarkana..... A	54.2	0	0	0	78	345	561	626	468	350	105	0	0	2533
Calif.	Bakersfield..... A	55.4	0	0	0	37	282	502	546	364	267	105	19	0	2122
	Bishop..... A	46.0	0	0	48	260	576	797	874	680	555	306	143	36	4275
	Blue Canyon .... A	42.2	28	37	108	347	594	781	896	795	806	597	412	195	5596
	Burbank ..... A	58.6	0	0	6	43	177	301	366	277	239	138	81	18	1646
	Eureka..... C	49.9	270	257	258	329	414	499	546	470	505	438	372	285	4643
	Fresno..... A	53.3	0	0	0	84	354	577	605	426	335	162	62	6	2611
	Long Beach ..... A	57.8	0	0	9	47	171	316	397	311	264	171	93	24	1803
	Los Angeles..... A	57.4	28	28	42	78	180	291	372	302	288	219	158	81	2061
	Los Angeles..... C	60.3	0	0	6	31	132	229	310	230	202	123	68	18	1349
	Mt. Shasta C	41.2	25	34	123	406	696	902	983	784	738	525	347	159	5722
	Oakland ..... A	53.5	53	50	45	127	309	481	527	400	353	255	180	90	2870
	Red Bluff..... A	53.8	0	0	0	53	318	555	605	428	341	168	47	0	2515
	Sacramento..... A	53.9	0	0	0	56	321	546	583	414	332	178	72	0	2502
	Sacramento..... C	54.4	0	0	0	62	312	533	561	392	310	173	76	0	2419
	Sandberg C	46.8	0	0	30	202	480	691	778	661	620	426	264	57	4209
	San Diego..... A	59.5	9	0	21	43	135	236	298	235	214	135	90	42	1458
	San Francisco... A	53.4	81	78	60	143	306	462	508	395	363	279	214	126	3015
	San Francisco... C	55.1	192	174	102	118	231	388	443	336	319	279	239	180	3001
	Santa Maria ..... A	54.3	99	93	96	146	270	391	459	370	363	282	233	165	2967
Colo.	Alamosa ..... A	29.7	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529
	Colorado Springs A	37.3	9	25	132	456	825	1032	1128	938	893	582	319	84	6423
	Denver..... A	37.6	6	9	117	428	819	1035	1132	938	887	558	288	66	6283
	Denver..... C	40.8	0	0	90	366	714	905	1004	851	800	492	254	48	5524
	Grand Junction .. A	39.3	0	0	30	313	786	1113	1209	907	729	387	146	21	5641
	Pueblo..... A	40.4	0	0	54	326	750	986	1085	871	772	429	174	15	5462
Conn.	Bridgeport..... A	39.9	0	0	66	307	615	986	1079	966	853	510	208	27	5617
	Hartford..... A	37.3	0	12	117	394	714	1101	1190	1042	908	519	205	33	6235
	New Haven..... A	39.0	0	12	87	347	648	1011	1097	991	871	543	245	45	5897
Del.	Wilmington..... A	42.5	0	0	51	270	588	927	980	874	735	387	112	6	4930
D.C.	Washington ..... A	45.7	0	0	33	217	519	834	871	762	626	288	74	0	4224
Fla.	Apalachicola C	61.2	0	0	0	16	153	319	347	260	180	33	0	0	1308
	Daytona Beach .. A	64.5	0	0	0	0	75	211	248	100	140	15	0	0	879
	Fort Myers..... A	68.6	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville ..... A	61.9	0	0	0	12	144	310	332	246	174	21	0	0	1239
	Key West..... A	73.1	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland..... C	66.7	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami..... A	71.1	0	0	0	0	0	65	74	56	19	0	0	0	214
	Miami Beach C	72.5	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando..... A	65.7	0	0	0	0	72	198	220	165	105	6	0	0	766
	Pensacola..... A	60.4	0	0	0	19	195	353	400	277	183	36	0	0	1463
	Tallahassee ..... A	60.1	0	0	0	28	198	360	375	286	202	36	0	0	1485
	Tampa..... A	66.4	0	0	0	0	60	171	202	148	102	0	0	0	683
	West Palm Beach A	68.4	0	0	0	0	6	65	87	64	31	0	0	0	253

Reprinted from *ASHRAE 1973* Systems Handbook, Chapter 43, "Energy Estimating Method."

a Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days* 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 Revisions to this publication, where available.

b Data for airport stations, A, and city stations, C, are both given where available.

c Data for Canadian cities where computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating degree days data were obtained using the National Research Council computer and a method devised by H.C.S. Thorn of the United States Weather Bureau. The heating degree days are based on the period from 1931 to 1960.

Appendix A, AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station	Avg. Winter Temp. °F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ga.	Athens.....A	51.8	0	0	12	115	405	632	642	529	431	141	22	0	2929
	Atlanta.....A	51.7	0	0	18	124	417	648	636	518	428	147	25	0	2961
	Augusta.....A	54.5	0	0	0	78	333	552	549	445	350	90	0	0	2397
	Columbus.....A	54.8	0	0	0	87	333	543	552	434	338	96	0	0	2383
	Macon.....A	56.2	0	0	0	71	297	502	505	403	295	63	0	0	2136
	Rome.....A	49.9	0	0	24	161	474	701	710	577	468	177	34	0	3326
	Savannah.....A	57.8	0	0	0	47	246	437	437	353	254	45	0	0	1819
	Thomasville.....C	60.0	0	0	0	25	198	366	394	305	208	33	0	0	1529
Hawaii	Libue.....A	72.7	0	0	0	0	0	0	0	0	0	0	0	0	0
	Honolulu.....A	74.2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hilo.....A	71.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	Boise.....A	39.7	0	0	132	415	792	1017	1113	854	722	438	245	81	5809
	Lewiston.....A	41.0	0	0	123	403	756	933	1063	815	694	426	239	90	5542
	Pocatello.....A	34.8	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033
Ill.	Cairo.....C	47.9	0	0	36	164	513	791	856	680	539	195	47	0	3821
	Chicago(O'Hare)A	35.8	0	12	117	381	807	1166	1265	1086	939	534	260	72	6639
	Chicago(Midway)A	37.5	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155
	Chicago.....C	38.9	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
	Moline.....A	36.4	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408
	Peoria.....A	38.1	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025
	Rockford.....A	34.8	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830
	Springfield.....A	40.6	0	0	72	291	696	1023	1135	935	769	354	136	18	5429
Ind.	Evansville.....A	45.0	0	0	66	220	606	896	955	767	620	237	68	0	4435
	Fort Wayne.....A	37.3	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205
	Indianapolis.....A	39.6	0	0	90	316	723	1051	1113	949	809	432	177	39	5699
	South Bend.....A	36.6	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439
Iowa	Burlington.....A	37.6	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114
	Des Moines.....A	35.5	0	6	96	363	828	1225	1370	1137	915	438	180	30	6588
	Dubuque.....A	32.7	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376
	Sioux City.....A	34.0	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951
	Waterloo.....A	32.6	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320
Kans.	Concordia.....A	40.4	0	0	57	276	705	1023	1163	935	781	372	149	18	5479
	Dodge City.....A	42.5	0	0	33	251	666	939	1051	840	719	354	124	9	4986
	Goodland.....A	37.8	0	6	81	381	810	1073	1166	955	884	507	236	42	6141
	Topeka.....A	41.7	0	0	57	270	672	980	1122	893	722	330	124	12	5182
	Wichita.....A	44.2	0	0	33	229	618	905	1023	804	645	270	87	6	4620
Ky.	Covington.....A	41.4	0	0	75	291	669	983	1035	893	756	390	149	24	5265
	Lexington.....A	43.8	0	0	54	239	609	902	946	818	685	325	105	0	4683
	Louisville.....A	44.0	0	0	54	248	609	890	930	818	682	315	105	9	4660
La.	Alexandria.....A	57.5	0	0	0	56	273	431	471	361	260	69	0	0	1921
	Baton Rouge....A	59.8	0	0	0	31	216	369	409	294	208	33	0	0	1560
	Lake Charles....A	60.5	0	0	0	19	210	341	381	274	195	39	0	0	1459
	New Orleans....A	61.0	0	0	0	19	192	322	363	258	192	39	0	0	1385
	New Orleans....C	61.8	0	0	0	12	165	291	344	241	177	24	0	0	1254
	Shreveport.....A	56.2	0	0	0	47	297	477	552	426	304	81	0	0	2184
Me.	Caribou.....A	24.4	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767
	Portland.....A	33.0	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511
Md.	Baltimore.....A	43.7	0	0	48	264	585	905	936	820	679	327	90	0	4654
	Baltimore.....C	46.2	0	0	27	189	486	806	859	762	629	288	65	0	4111
	Frederich.....A	42.0	0	0	66	307	624	955	995	876	741	384	127	12	5087
Mass.	Boston.....A	40.0	0	9	60	316	603	983	1088	972	846	513	208	36	5634
	Nantucket.....A	40.2	12	22	93	332	573	896	992	941	896	621	384	129	5891
	Pittsfield.....A	32.6	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578
	Worcester.....A	34.7	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969
Mich.	Alpena.....A	29.7	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506
	Detroit (City).....A	37.2	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
	Detroit (Wayne)..A	37.1	0	0	96	353	738	1088	1194	1061	933	534	239	57	6293
	Detroit (Willow Run).....A	37.2	0	0	90	357	750	1104	1190	1053	921	519	229	45	6258
	Escanaba.....C	29.6	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481
	Flint.....A	33.1	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377
	Grand Rapids...A	34.9	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894
	Lansing.....A	34.8	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909
	Marquette.....C	30.2	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393
	Muskegon.....A	36.0	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696
	Sault Ste. Marie..A	27.7	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048
Minn.	Duluth.....A	23.4	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000
	Minneapolis.....A	28.3	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
	Rochester.....A	28.8	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295
Miss.	Jackson.....A	55.7	0	0	0	65	315	502	546	414	310	87	0	0	2239
	Meridian.....A	55.4	0	0	0	81	339	518	543	417	310	81	0	0	2289
	Vicksburg.....C	56.9	0	0	0	53	279	462	512	384	282	69	0	0	2041
Mo.	Columbia.....A	42.3	0	0	54	251	651	967	1076	874	716	324	121	12	5046
	Kansas City.....A	43.9	0	0	39	220	612	905	1032	818	682	294	109	0	4711
	St. Joseph.....A	40.3	0	6	60	285	708	1039	1172	949	769	348	133	15	5484
	St. Louis.....A	43.1	0	0	60	251	627	936	1026	848	704	312	121	15	4900

State	Station		July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	St. Louis C	44.8	0	0	36	202	576	884	977	801	651	270	87	0	4484
	Springfield .....A	44.5	0	0	45	223	600	877	973	781	660	291	105	6	4900
Mont.	Billings.....A	34.5	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049
	Glasgow .....A	26.4	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996
	Great Falls .....A	32.8	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750
	Havre.....A	28.1	28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700
	Havre.....C	29.8	19	37	252	539	1014	1321	1528	1305	1116	612	304	135	8182
	Helena.....A	31.1	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129
	Kalispell .....A	31.4	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191
	Miles City .....A	31.2	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723
	Missoula .....A	31.5	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125
Neb.	Grand Island ....A	36.0	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530
	Lincoln.....C	38.8	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864
	Norfolk.....A	34.0	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979
	North Platte .....A	35.5	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684
	Omaha .....A	35.6	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612
	Scottsbluff.....A	35.9	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673
	Valentine.....A	32.6	9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425
Nev.	Elko .....A	34.0	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433
	Ely.....A	33.1	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733
	Las Vegas.....A	53.5	0	0	0	78	387	617	688	487	335	111	6	0	2709
	Reno .....A	39.3	43	87	204	490	801	1026	1073	823	729	510	357	189	6332
	Winnemucca ....A	36.7	0	34	210	536	876	1091	1172	916	837	573	363	153	6761
N.H.	Concord .....A	33.0	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383
	Mt. Washington Obsv..... -	15.2	493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817
N.J.	Atlantic City .....A	43.2	0	0	39	251	549	880	936	848	741	420	133	15	4812
	Newark .....A	42.8	0	0	30	248	573	921	983	876	729	381	118	0	4589
	Trenton C	42.4	0	0	57	264	576	924	989	885	753	399	121	12	4980
N.M.	Albuquerque ....A	45.0	0	0	12	229	642	868	930	703	595	288	81	0	4348
	Clayton .....A	42.0	0	6	66	310	699	899	986	812	747	429	183	21	5158
	Raton.....A	38.1	9	28	126	431	825	1048	1116	904	834	543	301	63	6228
	Roswell .....A	47.5	0	0	18	202	573	806	840	641	481	201	31	0	3793
	Silver City .....A	48.0	0	0	6	183	525	729	791	605	518	261	87	0	3705
N.Y.	Albany.....A	34.6	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875
	Albany.....C	37.2	0	9	102	375	699	1104	1218	1072	908	498	186	30	6201
	Binghamton .....A	33.9	22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286
	Binghamton C	36.6	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451
	Buffalo.....A	34.5	19	37	141	440	777	1156	1256	1145	1039	645	329	78	7062
	New York (Cent. Park)	42.8	0	0	30	233	540	902	986	885	760	408	118	9	4871
	New York (La Guardia).....A	43.1	0	0	27	223	528	887	973	879	750	414	124	6	4811
	New York (Kennnedy) .....A	41.4	0	0	36	248	564	933	1029	935	815	480	167	12	5219
	Rochester.....A	35.4	9	31	126	415	747	1125	1234	1123	1014	597	279	48	6748
	Schenectady C	35.4	0	22	123	422	756	1159	1283	1131	970	543	211	30	6650
	Syracuse.....A	35.2	6	28	132	415	744	1153	1271	1140	1004	570	248	45	6756
N.C.	Asheville.....C	46.7	0	0	48	245	555	775	784	683	592	273	87	0	4042
	Cape Hatteras....	53.3	0	0	0	78	273	521	580	518	440	177	25	0	2612
	Charlotte.....A	50.4	0	0	6	124	438	691	691	582	481	156	22	0	3191
	Greensboro .....A	47.5	0	0	33	192	513	778	784	672	552	234	47	0	3805
	Raleigh .....A	49.4	0	0	21	164	450	716	725	616	487	180	34	0	3393
	Wilmington.....A	54.6	0	0	0	74	291	521	546	462	357	96	0	0	2347
	Winston-Salem..A	48.4	0	0	21	171	483	747	753	652	524	207	37	0	3595
N.D.	Bismarck.....A	26.6	34	28	222	577	1083	1463	1708	1442	1203	645	329	117	8851
	Devils Lake.....C	22.4	40	53	273	642	1191	1634	1872	1579	1345	753	381	138	9901
	Fargo .....A	24.8	28	37	219	574	1107	1569	1789	1520	1262	690	332	99	9226
	Williston.....A	25.2	31	43	261	601	1122	1513	1758	1473	1262	681	357	141	9243
Ohio	Akron-Canton ...A	38.1	0	9	96	381	726	1070	1138	1016	871	489	202	39	6037
	Cincinnati C	45.1	0	0	39	208	558	862	915	790	642	294	96	6	4410
	Cleveland .....A	37.2	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351
	Columbus.....A	39.7	0	6	84	347	714	1039	1088	949	809	426	171	27	5660
	Columbus.....C	41.5	0	0	57	285	651	977	1032	902	760	396	136	15	5211
	Dayton.....A	39.8	0	6	78	310	696	1045	1097	955	809	429	167	30	5622
	Mansfield .....A	36.9	9	22	114	397	768	1110	1169	1042	924	543	245	60	6403
	Sandusky C	39.1	0	6	66	313	684	1032	1107	991	868	495	198	36	5796
	Toledo .....A	36.4	0	16	117	406	792	1138	1200	1056	924	543	242	60	6494
	Youngstown.....A	36.8	6	19	120	412	771	1104	1169	1047	921	540	248	60	6417
Okla.	Oklahoma City...A	48.3	0	0	15	164	498	766	868	664	527	189	34	0	3725
	Tulsa .....A	47.7	0	0	18	158	522	787	893	683	539	213	47	0	3860
Ore.	Astoria.....A	45.6	146	130	210	375	561	679	753	622	636	480	363	231	5186
	Burns.....C	35.9	12	37	210	515	867	1113	1246	988	856	570	366	177	6957
	Eugene .....A	45.6	34	34	129	366	585	719	803	627	589	426	279	135	4726
	Mescham .....A	34.2	84	124	288	580	918	1091	1209	1005	983	726	527	339	7874
	Medford.....A	43.2	0	0	78	372	678	871	918	697	642	432	242	78	5008
	Pendleton .....A	42.6	0	0	111	350	711	884	1017	773	617	396	205	63	5127
	Portland.....A	45.6	25	28	114	335	597	735	825	644	586	396	245	105	4635
	Portland.....C	47.4	12	16	75	267	534	679	769	594	536	351	198	78	4109

Appendix A, AVERAGE MONTHLY AND YEARLY DEGREE DAYS, CONTINUED

State	Station	Avg. Winter Temp. °F	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
	Roseburg .....A	46.3	22	16	105	329	567	713	766	608	570	405	267	123	4491
	Salem .....A	45.4	37	31	111	338	594	729	822	647	611	417	273	144	4754
Pa.	Allentown .....A	38.9	0	0	90	353	693	1045	1116	1002	849	471	167	24	5810
	Erie.....A	36.8	0	25	102	391	714	1063	1169	1081	973	585	288	60	6451
	Harrisburg .....A	41.2	0	0	63	298	648	992	1045	907	766	396	124	12	5251
	Philadelphia.....A	41.8	0	0	60	297	620	965	1016	889	747	392	118	40	5144
	Philadelphia.....C	44.5	0	0	30	205	513	856	924	823	691	351	93	0	4486
	Pittsburgh.....A	38.4	0	9	105	375	726	1063	1119	1002	874	480	195	39	5987
	Pittsburgh.....C	42.2	0	0	60	291	615	930	983	885	763	390	124	12	5053
	Reading C	42.4	0	0	54	257	597	939	1001	885	735	372	105	0	4945
	Scranton.....A	37.2	0	19	132	434	762	1104	1156	1028	893	498	195	33	6254
	Williamsport.....A	38.5	0	9	111	375	717	1073	1122	1002	856	468	177	24	5934
R.I.	Block Island.....A	40.1	0	16	78	307	594	902	1020	955	877	612	344	99	5804
	Providence.....A	38.8	0	16	96	372	660	1023	1110	988	868	534	236	51	5954
S.C.	Charleston.....A	56.4	0	0	0	59	282	471	487	389	291	54	0	0	2033
	Charleston.....C	57.9	0	0	0	34	210	425	443	367	273	42	0	0	1794
	Columbia .....A	54.0	0	0	0	84	345	577	570	470	357	81	0	0	2484
	Florence .....A	54.5	0	0	0	78	315	552	552	459	347	84	0	0	2387
	Greenville-Spartenburg.....A	51.6	0	0	6	121	399	651	660	546	446	132	19	0	2980
S.D.	Huron.....A	28.8	9	12	165	508	1014	1432	1628	1355	1125	600	288	87	8223
	Rapid City.....A	33.4	22	12	165	481	897	1172	1333	1145	1051	615	326	126	7345
	Sioux Falls .....A	30.6	19	25	168	462	972	1361	1544	1285	1082	573	270	78	7839
Tenn.	Bristol.....A	46.2	0	0	51	236	573	828	828	700	598	261	68	0	4143
	Chattanooga ....A	50.3	0	0	18	143	468	698	722	577	453	150	25	0	3254
	Knoxville.....A	49.2	0	0	30	171	489	725	732	613	493	198	43	0	3494
	Memphis.....A	50.5	0	0	18	130	447	698	729	585	456	147	22	0	3232
	Memphis.....C	51.6	0	0	12	102	396	648	710	568	434	129	16	0	3015
	Nashville.....A	48.9	0	0	30	158	495	732	778	644	512	189	40	0	3578
	Oak Ridge.....C	47.7	0	0	39	192	531	772	778	669	552	228	56	0	3817
Tex.	Abilene .....A	53.9	0	0	0	99	366	586	642	470	347	114	0	0	2624
	Amarillo.....A	47.0	0	0	18	205	570	797	877	664	546	252	56	0	3985
	Austin.....A	59.1	0	0	0	31	225	388	468	325	223	51	0	0	1711
	Brownsville.....A	67.7	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi ...A	64.6	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas.....A	55.3	0	0	0	62	321	524	601	440	319	90	6	0	2363
	El Paso .....A	52.9	0	0	0	84	414	648	685	445	319	105	0	0	2700
	Fort Worth.....A	55.1	0	0	0	65	324	536	614	448	319	99	0	0	2405
	Galveston.....A	62.2	0	0	0	6	147	276	360	263	189	33	0	0	1274
	Galveston.....C	62.0	0	0	0	0	138	270	350	258	189	30	0	0	1235
	Houston.....A	61.0	0	0	0	6	183	307	384	288	192	36	0	0	1396
	Houston.....C	62.0	0	0	0	0	165	288	363	258	174	30	0	0	1278
	Laredo.....A	66.0	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock .....A	48.8	0	0	18	174	513	744	800	613	484	201	31	0	3578
	Midland.....A	53.8	0	0	0	87	381	592	651	468	322	90	0	0	2591
	Port Arthur .....A	60.5	0	0	0	22	207	329	384	274	192	39	0	0	1447
	San Angelo.....A	56.0	0	0	0	68	318	536	567	412	288	66	0	0	2255
	San Antonio.....A	60.1	0	0	0	31	204	363	428	286	195	39	0	0	1546
	Victoria .....A	62.7	0	0	0	6	150	270	344	230	152	21	0	0	1173
	Waco .....A	57.2	0	0	0	43	270	456	536	389	270	66	0	0	2030
	Wichita Falls.....A	53.0	0	0	0	99	381	632	698	518	378	120	6	0	2832
Utah	Milford .....A	36.5	0	0	99	443	867	1141	1252	988	822	519	279	87	6497
	Salt Lake City....A	38.4	0	0	81	419	849	1082	1172	910	763	459	233	84	6052
	Wendover.....A	39.1	0	0	48	372	822	1091	1178	902	729	408	177	51	5778
Vt.	Burlington.....A	29.4	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269
Va.	Cape Henry C	50.0	0	0	0	112	360	645	694	633	536	246	53	0	3279
	Lynchburg.....A	46.0	0	0	51	223	540	822	849	731	605	267	78	0	4166
	Norfolk.....A	49.2	0	0	0	136	408	698	738	655	533	216	37	0	3421
	Richmond.....A	47.3	0	0	36	214	495	784	815	703	546	219	53	0	3865
	Roanoke .....A	46.1	0	0	51	229	549	825	834	722	614	261	65	0	4150
Wash.	Olympia.....A	44.2	68	71	198	422	636	753	834	675	645	450	307	177	5236
	Seattle-Tacoma..A	44.2	56	62	162	391	633	750	828	678	657	474	295	159	5145
	Seattle.....C	46.9	50	47	129	329	543	657	738	599	577	396	242	117	4424
	Spokane .....A	36.5	9	25	168	493	879	1082	1231	980	834	531	288	135	6655
	Walla Walla.....C	43.8	0	0	87	310	681	843	986	745	589	342	177	45	4805
	Yakima.....A	39.1	0	12	144	450	828	1039	1163	868	713	435	220	69	5941
W. Va.	Charleston .....A	44.8	0	0	63	254	591	865	880	770	648	300	96	9	4476
	Elkins.....A	40.1	9	25	135	400	729	992	1008	896	791	444	198	48	5675
	Huntington .....A	45.0	0	0	63	257	585	856	880	764	636	294	99	12	4446
	Parkersburg.....C	43.5	0	0	60	264	606	905	942	826	691	339	115	6	4754
Wisc.	Green Bay .....A	30.3	28	50	174	484	924	1333	1494	1313	1141	654	335	99	8029
	La Crosse.....A	31.5	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589
	Madison .....A	30.9	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863
	Milwaukee .....A	32.6	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Wyo.	Casper.....A	33.4	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410
	Cheyenne.....A	34.2	28	37	219	543	909	1085	1212	1042	1026	702	428	150	7381
	Lander.....A	31.4	6	19	204	555	1020	1299	1417	1145	1017	654	381	153	7870
	Sheridan.....A	32.5	25	31	219	539	948	1200	1355	1154	1051	642	366	150	7680

CANADA

Prov.	Station	Avg. Winter Temp.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Alta.	Banff C		220	295	498	797	1185	1485	1624	1364	1237	855	589	402	10551
	Calgary .....A		109	186	402	719	1110	1389	1575	1379	1268	798	477	291	9703
	Edmonton.....A		74	180	411	738	1215	1603	1810	1520	1330	765	400	222	10268
	Lethbridge .....A		56	112	318	611	1011	1277	1497	1291	1159	696	403	213	8644
B.C.	Kamloops.....A		22	40	189	546	894	1138	1314	1057	818	462	217	102	6799
	Prince George*..A		236	251	444	747	1110	1420	1612	1319	1122	747	468	279	9755
	Prince Rupert....C		273	248	339	539	708	868	936	808	812	648	493	357	7029
	Vancouver*.....A		81	87	219	456	657	787	862	723	676	501	310	156	5515
	Victoria*.....A		136	140	225	462	663	775	840	718	691	504	341	204	5699
	Victoria C		172	184	243	426	607	723	805	668	660	487	354	250	5579
Man.	Brandon*.....A		47	90	357	747	1290	1792	2034	1737	1476	837	431	198	11036
	Churchill .....A		360	375	681	1082	1620	2248	2558	2277	2130	1569	1153	675	16728
	The Pas.....C		59	127	429	831	1440	1981	2232	1853	1624	969	508	228	12281
	Winnipeg.....A		38	71	322	683	1251	1757	2008	1719	1465	813	405	147	10679
N.B.	Fredericton*.....A		78	68	234	592	915	1392	1541	1379	1172	753	406	141	8671
	Moncton C		62	105	276	611	891	1342	1482	1336	1194	789	468	171	8727
	St. John.....C		109	102	246	527	807	1194	1370	1229	1097	756	490	249	8219
Nod.	Argentia .....A		260	167	294	564	750	1001	1159	1085	1091	879	707	483	8440
	Corner Brook....C		102	133	324	642	873	1194	1358	1283	1212	885	639	333	8978
	Gander .....A		121	152	330	670	909	1231	1370	1266	1243	939	657	366	9254
	Goose*.....A		130	205	444	843	1227	1745	1947	1689	1494	1074	741	348	11887
	St. John's*.....A		186	180	342	651	831	1113	1262	1170	1187	927	710	432	8991
N.W.T.	Aklavik.....C		273	459	807	1414	2064	2530	2632	2336	2282	1674	1063	483	18017
	Fort Norman.....C		164	341	666	1234	1959	2474	2592	2209	2058	1386	732	294	16109
	Resolution Island C		843	831	900	1113	1311	1724	2021	1850	1817	1488	1181	942	16021
N.S.	Halifax.....C		58	51	180	457	710	1074	1213	1122	1030	742	487	237	7361
	Sydney .....A		62	71	219	518	765	1113	1262	1206	1150	840	567	276	8049
	Yarmouth .....A		102	115	225	471	696	1029	1156	1065	1004	726	493	258	7340
Ont.	Cochrane C		96	180	405	760	1233	1776	1978	1701	1528	963	570	222	11412
	Fort William .....A		90	133	366	694	1140	1597	1792	1557	1380	876	543	237	10405
	Kapuskasing C		74	171	405	756	1245	1807	2037	1735	1562	978	580	222	11572
	Kitchener C		16	59	177	505	855	1234	1342	1226	1101	663	322	66	7566
	London .....A		12	43	159	477	837	1206	1305	1198	1066	648	332	66	7349
	North Bay C		37	90	267	608	990	1507	1680	1463	1277	780	400	120	9219
	Ottawa.....C		25	81	222	567	936	1469	1624	1441	1231	708	341	90	8735
	Toronto C		7	18	151	439	760	1111	1233	1119	1013	616	298	62	6827
P.E.I.	Charlottetown ...C		40	53	198	518	804	1215	1380	1274	1169	813	496	204	8164
	Summerside C		47	84	216	546	840	1246	1438	1291	1206	841	518	216	8488
Que.	Arvida C		102	136	327	682	1074	1659	1879	1619	1407	891	521	231	10528
	Montreal*.....A		9	43	165	521	882	1392	1566	1381	1175	684	316	69	8203
	Montreal C		16	28	165	496	864	1355	1510	1328	1138	657	288	54	7899
	Quebec*.....A		56	84	273	636	996	1516	1665	1477	1296	819	428	126	9372
	Quebec C		40	68	243	592	972	1473	1612	1418	1228	780	400	111	8937
Sasks.	Prince Albert ....A		81	136	414	797	1368	1872	2108	1763	1559	867	446	219	11630
	Regina.....A		78	93	360	741	1284	1711	1965	1687	1473	804	409	201	10806
	Saskatoon C		56	87	372	750	1302	1758	2006	1689	1463	798	403	186	10870
Y.T.	Dawson.....C		164	326	645	1197	1875	2415	2561	2150	1838	1068	570	258	15067
	Mayo Landing ...C		208	366	648	1135	1794	2325	2427	1992	1665	1020	590	294	14454

NOT AVAILABLE

*The data for these normals were from the full ten-year period 1951-1960 adjusted to the standard normal period 1931-1960.

Appendix B | INSOLATION MAP

48°
40°
32°
Caribou
Internat'l Falls
Duluth
Sault Ste. Marie
MINNESOTA
NEW HAMPSHIRE
MAINE
VERMONT
Burlington
Massena
Portland
NEW YORK
Concord
Lynn
Boston
Natick
Schenectady
Syracuse
Albany
Amherst
Blue Hill
Providence
Newport
Hartford
RHODE ISLAND
CONNECTICUT
St. Cloud
WISCONSIN
St. Paul
Eau Claire
Green Bay
Traverse City
MICHIGAN
Rochester
Buffalo
Ithaca
Binghamton
La Crosse
Grand Rapids
East Lansing
Flint
Milwaukee
Madison
Lansing
Detroit
Avoca
New York
Erie
PENNSYLVANIA
Newark
Allentown
Trenton
Lakehurst
Sioux City
Mason City
IOWA
Put-in-Bay
State College
Harrisburg
Chicago
Toledo
Cleveland
Akron
Youngstown
Philadelphia
Ames
Lemont
South Bend
Indianapolis
Pittsburgh
Atlantic City
Wilmington
Des Moines
Moline
Peoria
OHIO
Baltimore
Annapolis
Silver Hill
Washington
INDIANA
Columbus
ILLINOIS
Dayton
Fort Wayne
Parkersburg
Springfield
Covington
WEST VIRGINIA
Mt. Weather
Kansas City
Richmond
Columbia
Lexington
Charleston
Norfolk
Evansville
Louisville
St. Louis
Roanoke
MISSOURI
KENTUCKY
Raleigh-Durham
Raleigh
Cape Hatteras
Springfield
Greensboro
Oak Ridge
NORTH CAROLINA
Asheville
Charlotte
Cherry Point
Nashville
TENNESSEE
Chattanooga
Grnvle.-Sptnbrg
Fort Smith
Memphis
Columbia
Little Rock
SOUTH CAROLINA
Atlanta
ARKANSAS
Augusta
Birmingham
Charleston
Griffin
MISSISSIPPI
ALABAMA
Macon
Meridian
Montgomery
Savannah
Shreveport
Jackson
GEORGIA
LOUISIANA
Jacksonville
Lufkin
Mobile
Tallahassee
Gainesville
Baton Rouge
Pensacola
Daytona Beach
Port Arthur
Lake Charles
Apalachicola
Houston
New Orleans
Orlando
FLORIDA
Tampa
Miami

Appendix B | INSOLATION AND PERCENT DIFFUSE TABLES[1] | BTU per sq. ft. per day / % DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
ALABAMA													
Birmingham	33.6°	706/53	967/48	1295/45	1672/40	1855/40	1917/40	1809/42	1722/40	1454/41	1210/39	858/45	661/51
Mobile	30.7°	828/48	1099/45	1406/41	1721/39	1871/39	1867/41	1714/45	1640/44	1449/44	1298/38	955/44	759/49
Montgomery	32.3°	751/51	1013/47	1339/44	1728/39	1896/39	1971/38	1839/41	1744/40	1467/42	1261/38	915/44	719/49
ALASKA													
Annette	55.0°	232/50	424/53	870/42	1342/41	1611/45	1615/49	1615/47	1257/50	951/47	450/58	217/62	151/59
Bethel	60.8°	136/41	413/33	1040/18	1640/22	1692/40	1655/48	1364/55	936/60	734/53	431/46	166/48	85/44
Fairbanks	64.8°	70/23	280/36	859/20	1419/28	1758/36	1943/39	1637/45	1338/41	678/51	317/48	100/38	22/32
Matanuska	61.6°	118/42	339/42	892/28	1312/37	1607/42	1703/46	1508/49	1158/50	730/53	369/51	140/51	55/55
ARIZONA													
Page	36.6°	1106/18	1408/19	1939/13	2278/16	2562/16	2606/19	2507/20	2197/23	1902/21	1482/21	1143/20	896/27
Phoenix	33.4°	1020/31	1374/27	1813/22	2353/15	2674/13	2738/14	2485/21	2291/21	2014/20	1575/21	1150/27	932/32
Prescott	34.6°	1015/29	1334/27	1776/23	2274/18	2628/15	2761/14	2308/27	2090/28	1953/21	1542/21	1139/24	926/30
Tucson	32.1°	1098/29	1431/25	1863/22	2362/16	2670/13	2728/14	2340/25	2181/25	1978/22	1601/22	1207/25	995/31
Winslow	35.0°	984/30	1326/27	1779/22	2282/18	2593/16	2709/15	2345/25	2139/25	1927/21	1512/22	1118/25	894/31
Yuma	32.7°	1095/28	1442/24	1918/19	2411/14	2726/12	2812/12	2451/22	2327/20	2050/19	1622/20	1214/24	999/29
ARKANSAS													
Fort Smith	35.3°	743/47	999/45	1311/42	1615/41	1911/38	2088/34	2064/34	1876/34	1504/39	1200/38	851/42	682/47
Little Rock	34.7°	731/49	1002/45	1312/42	1610/42	1928/38	2105/34	2031/36	1860/36	1517/38	1228/37	847/44	673/49
CALIFORNIA													
Arcata	41.0°	528/53	793/48	1132/46	1586/40	1841/40	1960/39	1807/42	1578/44	1341/41	935/45	593/51	469/54
Bakersfield	35.4°	766/45	1101/38	1594/30	2093/24	2508/19	2748/14	2681/14	2419/16	1991/19	1457/24	941/37	677/47
Daggett	34.9°	957/32	1279/29	1772/23	2273/18	2590/16	2764/14	2602/18	2381/18	2007/19	1515/22	1084/28	875/33
Davis	38.5°	583/53	944/42	1482/31	1947/28	2345/23	2588/21	2544/19	2252/21	1836/22	1283/29	796/53	546/51
El Toro	33.7°	947/36	1235/33	1609/31	1928/31	2068/33	2193/31	2362/29	2154/25	1736/30	1356/32	1026/34	869/37
Fresno	36.8°	645/51	999/42	1524/31	1965/28	2308/25	2529/21	2524/20	2274/21	1871/22	1355/28	841/53	549/55
Inyokern	35.6°	1150/16	1545/13	2131/6	2584/6	2903/5	3082/4	2890/8	2721/5	2389/2	1784/6	1349/8	1087/14
Long Beach	33.8°	927/37	1214/34	1609/31	1936/30	2063/33	2139/33	2298/27	2098/28	1699/31	1325/33	1003/36	846/38
Los Angeles	33.9°	925/37	1213/34	1618/30	1950/30	2058/33	2118/33	2306/27	2078/28	1680/32	1316/33	1003/36	848/37
Mt. Shasta	41.3°	560/49	857/44	1250/40	1755/33	2185/29	2435/24	2576/18	2212/21	1734/24	1154/31	659/46	505/49
Needles	34.8°	984/30	1353/25	1824/20	2316/16	2650/14	2790/13	2540/19	2276/21	2013/19	1537/21	1123/25	913/30
Oakland	37.7°	707/45	1017/40	1456/33	1921/29	2210/28	2348/27	2321/27	2052/28	1700/29	1211/33	822/40	646/45
Pasadena	34.1°	925/36	1228/33	1618/29	1876/32	2097/32	2138/33	2337/25	2208/23	1777/28	1349/31	999/34	870/36
Point Mugu	34.1°	926/36	1220/33	1634/29	1950/30	2016/34	2053/36	2117/32	1934/33	1607/36	1295/34	1005/34	856/37
Riverside	33.9°	1014/30	1353/27	1762/24	1994/29	2297/25	2507/22	2481/21	2278/21	1972/21	1500/24	1176/24	995/27
Sacramento	38.5°	596/53	939/44	1457/33	2002/25	2433/21	2682/16	2687/14	2367/16	1906/19	1314/27	781/41	538/53
San Diego	32.7°	975/36	1265/33	1631/31	1935/31	2001/36	2061/36	2185/30	2056/29	1716/32	1373/32	1062/33	903/36
San Francisco	37.8°	707/45	1008/40	1454/33	1919/29	2224/28	2375/27	2390/24	2115/25	1741/27	1225/33	821/40	642/45
San Jose	37.3°	663/49	980/42	1301/41	1787/34	2115/31	2207/31	2247/29	1979/31	1691/29	1149/38	956/46	638/47
Santa Maria	34.9°	853/40	1140/37	1581/32	1920/32	2139/32	2347/27	2340/25	2105/27	1729/30	1353/30	973/36	803/38
Sunnyvale	37.4°	737/44	1036/39	1485/32	1943/29	2275/27	2451/24	2440/22	2165/24	1758/27	1248/32	843/39	660/45
COLORADO													
Boulder	40.0°	741/37	988/38	1478/30	1696/37	1696/45	1935/40	1917/39	1618/42	1519/34	1143/34	818/36	671/37
Colo. Springs	38.8°	890/28	1177/28	1549/28	1930/27	2127/31	2367/27	2210/30	2024/29	1758/25	1358/24	944/29	781/30
Denver	39.7°	840/33	1127/30	1530/29	1879/29	2134/30	2350/27	2272/27	2044/28	1726/26	1300/25	883/30	731/33
Eagle	39.6°	754/37	1077/32	1500/30	1931/28	2254/27	2507/22	2385/24	2083/27	1766/24	1307/25	868/32	690/36
Grand Junction	39.1°	791/34	1118/31	1552/28	1985/27	2378/22	2597/20	2464/22	2180/23	1833/22	1344/24	918/30	731/33
Grand Lake	40.3°	782/32	1154/27	1559/25	1888/29	2035/33	2330/28	2212/28	1862/30	1755/24	1331/23	863/31	678/36
Pueblo	38.3°	894/29	1171/30	1563/28	1955/28	2161/30	2433/24	2310/27	2101/27	1778/24	1360/24	953/29	782/31
CONNECTICUT													
Hartford	41.9°	477/56	714/53	978/53	1314/50	1567/48	1685/48	1648/47	1420/49	1154/49	852/48	497/58	384/60
DELAWARE													
Wilmington	39.7°	571/51	827/48	1148/46	1479/45	1709/45	1882/41	1822/42	1613/42	1317/44	984/44	644/50	489/55
DC													
Washington	38.8°	571/54	815/50	1124/48	1458/46	1717/44	1899/41	1817/42	1617/44	1340/44	1003/44	651/50	481/57
FLORIDA													
Apalachicola	29.7°	852/48	1125/45	1473/40	1877/34	2090/32	1997/37	1812/42	1686/42	1534/40	1370/36	1039/40	817/47
Daytona Beach	29.2°	958/42	1213/40	1547/37	1883/34	1966/38	1825/42	1783/42	1681/42	1477/44	1250/42	1035/41	870/45
Gainesville	29.6°	1025/38	1353/33	1640/33	1987/30	2160/30	2006/37	1917/39	1873/36	1637/37	1357/37	1172/32	936/40
Jacksonville	30.4°	899/45	1162/41	1521/37	1854/34	1955/37	1884/41	1801/42	1693/42	1441/44	1222/42	995/41	817/46
Miami	25.8°	1057/42	1313/39	1603/37	1858/36	1842/40	1707/46	1762/44	1629/45	1456/46	1301/42	1117/41	1019/41
Orlando	28.5°	999/41	1242/40	1581/36	1897/33	1987/36	1830/42	1800/42	1672/44	1495/42	1303/40	1095/39	925/42
Pensacola	30.5°	922/44	1183/40	1493/38	1876/33	2072/33	2094/34	1979/37	1876/36	1585/38	1452/31	1025/40	826/46
Tallahassee	30.4°	876/46	1136/42	1478/39	1828/36	1935/38	1882/41	1747/44	1674/42	1492/42	1317/38	1007/41	813/47
Tampa	28.0°	1010/41	1258/40	1593/36	1907/33	1997/36	1847/41	1751/44	1652/44	1491/44	1345/39	1107/39	935/42
GEORGIA													
Atlanta	33.6°	717/51	969/48	1302/44	1685/39	1853/40	1911/40	1811/42	1707/41	1421/42	1199/40	882/44	674/50
Augusta	33.4°	750/49	1014/46	1338/42	1728/38	1864/40	1903/40	1803/42	1666/42	1409/44	1219/39	916/41	720/48
Griffin	33.2°	877/41	1113/40	1430/39	1913/31	2127/31	2138/33	2061/34	1928/33	1611/36	1372/31	1062/32	774/44
Macon	32.7°	769/49	1019/46	1362/42	1734/38	1884/39	1918/40	1784/44	1716/41	1438/42	1246/39	939/41	728/48
Savannah	32.1°	907/41	1158/40	1486/38	1906/32	2075/33	2042/36	1976/37	1847/37	1486/41	1283/38	977/40	789/45
HAWAII													
Hilo	19.7°	1120/40	1246/40	1348/40	1434/40	1553/40	1658/40	1624/45	1592/45	1546/40	1372/40	1104/40	1019/45
Honolulu	21.3°	1180/40	1396/35	1621/35	1796/35	1949/30	2004/30	2002/30	1966/30	1810/30	1540/30	1766/35	1132/35
IDAHO													
Boise	43.6°	485/51	839/41	1302/34	1825/30	2275/25	2461/23	2611/16	2195/21	1736/21	1137/29	628/44	437/51
Pocatello	42.9°	539/48	881/39	1370/32	1819/30	2279/25	2478/23	2598/16	2238/20	1768/21	1202/25	689/39	476/48
Twin Falls	40.6°	601/48	885/44	1309/38	1703/36	2035/33	2183/32	2219/29	1991/29	1593/31	1054/39	649/48	483/54
ILLINOIS													
Chicago	42.0°	506/53	759/49	1106/46	1456/45	1788/41	2006/38	1942/38	1718/38	1353/40	969/41	565/51	402/58
Lemont	41.7°	630/42	855/44	1202/41	1438/46	1832/40	2038/37	1943/38	1792/36	1416/38	977/41	579/51	483/50

1. Source Data From Klein, Beckman and Duffie, "Monthly Average Solar Radiation on Inclined Surfaces, E. Report #42-2" University of Wisconsin, Revised 1978.

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Moline	41.4°	534/51	812/47	1117/46	1458/45	1752/42	1968/39	1937/38	1714/39	1356/40	995/40	594/50	432/56
Peoria	40.7°	601/47	840/46	1187/44	1556/41	1876/39	2112/34	2075/33	1851/34	1500/34	1102/36	682/45	512/50
Springfield	39.8°	585/50	860/46	1133/46	1514/44	1864/39	2096/34	2057/34	1804/36	1453/38	1067/39	676/47	490/54
INDIANA													
Evansville	38.0°	573/55	822/50	1150/47	1500/45	1781/42	1981/38	1919/39	1734/39	1403/41	1087/40	682/50	498/57
Fort Wayne	41.0°	455/59	697/55	981/53	1360/49	1670/46	1840/42	1786/44	1593/44	1272/45	924/46	516/58	369/64
Indianapolis	39.7°	495/58	747/54	1036/51	1397/48	1687/45	1866/42	1805/42	1642/41	1323/44	977/45	579/55	417/62
South Bend	41.7°	416/62	660/56	992/51	1387/47	1721/44	1921/40	1851/41	1665/40	1290/44	909/46	497/58	340/65
IOWA													
Ames	42.0°	642/40	933/38	1205/41	1486/44	1770/42	1994/38	1976/37	1696/39	1353/40	1010/39	689/41	527/46
Des Moines	41.5°	580/47	860/44	1180/42	1556/41	1866/39	2123/34	2096/33	1826/34	1433/37	1067/37	653/45	487/50
Mason City	43.1°	553/46	836/42	1167/41	1517/41	1894/38	2112/34	2083/33	1832/33	1404/37	1010/37	600/47	443/51
Sioux City	42.4°	568/47	841/44	1169/42	1577/40	1900/38	2122/34	2120/32	1844/33	1420/37	1037/37	642/45	469/50
KANSAS													
Dodge City	37.8°	826/36	1121/33	1476/32	1884/31	2089/32	2356/27	2294/27	2054/28	1685/29	1300/29	893/34	732/38
Manhattan	39.2°	708/41	973/40	1272/41	1596/40	1943/37	2031/37	1957/38	1939/31	1512/36	1077/39	837/36	575/48
Topeka	39.1°	681/45	940/42	1256/41	1640/39	1914/38	2125/34	2127/32	1909/32	1515/36	1146/36	771/41	583/47
Wichita	37.6°	783/40	1058/40	1405/35	1782/30	2035/35	2264/30	2238/28	2031/27	1616/30	1249/30	870/35	690/40
KENTUCKY													
Covington	39.1°	372/69	512/68	1036/51	1489/45	1873/39	2142/33	2470/21	2016/29	1471/37	866/51	516/60	299/73
Lexington	38.0°	545/57	779/54	1099/49	1478/46	1746/44	1896/41	1849/41	1685/41	1361/42	1043/42	657/51	485/58
Louisville	38.2°	545/57	789/53	1102/49	1466/46	1719/44	1902/41	1836/41	1679/41	1360/42	1042/42	652/51	488/57
LOUISIANA													
Baton Rouge	30.5°	785/51	1053/47	1378/44	1680/41	1870/39	1925/39	1744/45	1676/42	1463/42	1301/38	919/46	736/51
Lake Charles	30.2°	728/55	1009/49	1313/46	1569/45	1848/40	1969/38	1787/42	1656/44	1484/42	1380/34	916/47	705/54
New Orleans	30.0°	834/49	1111/45	1414/42	1779/38	1966/37	2002/37	1812/42	1715/41	1513/41	1334/37	972/44	779/49
Shreveport	32.4°	833/46	1028/46	1394/41	1721/39	2020/34	2006/37	2072/33	1917/34	1530/39	1312/36	896/45	730/49
MAINE													
Caribou	46.9°	425/50	726/44	1132/39	1407/44	1565/48	1749/46	1749/44	1486/45	1093/48	682/53	368/62	318/57
Portland	43.6°	450/55	682/53	969/51	1303/49	1567/48	1710/47	1658/47	1460/47	1157/47	822/48	459/58	363/59
MARYLAND													
Annapolis	39.0°	645/47	896/45	1254/41	1545/42	1799/41	2053/37	1998/37	1729/39	1411/40	1084/39	697/47	571/48
Baltimore	39.2°	586/51	839/48	1161/46	1487/45	1713/45	1878/41	1822/42	1598/44	1330/44	997/44	660/49	499/55
Silver Hill	38.8°	671/46	900/45	1253/42	1615/40	1891/38	2046/37	1902/39	1692/40	1463/38	1087/39	745/44	600/46
MASSACHUSETTS													
Amherst	42.2°	428/60	652/56	1106/46	1279/51	1589/48	1895/41	1902/39	1622/41	1217/46	922/44	564/51	457/53
Blue Hill	42.2°	575/46	792/47	1121/45	1397/47	1736/44	1906/41	1843/41	1600/40	1298/40	918/45	583/50	476/50
Boston	42.4°	476/55	709/53	1015/50	1325/49	1619/47	1816/44	1748/45	1486/47	1259/44	889/46	503/57	402/57
Lynn	42.5°	435/59	770/48	1106/46	1453/45	1674/45	1983/39	1987/37	1556/44	1253/44	852/48	490/57	369/60
Natick	42.3°	560/47	855/42	1202/41	1441/45	1843/39	1508/54	1891/40	1645/39	1323/41	962/41	542/54	494/48
MICHIGAN													
Detroit	42.2°	417/60	680/54	999/51	1398/47	1714/44	1865/42	1834/41	1574/44	1252/45	875/47	473/59	343/64
East Lansing	42.7°	446/57	774/47	1139/44	1323/49	1780/41	2016/38	1991/37	1718/38	1375/38	940/42	501/56	398/57
Flint	43.0°	383/63	636/56	956/53	1339/49	1657/46	1812/44	1795/42	1554/44	1195/46	829/49	429/62	309/66
Grand Rapids	42.9°	369/64	648/58	1014/49	1411/46	1754/42	1955/39	1913/39	1675/40	1261/44	858/47	446/60	311/66
Lansing	42.8°	498/53	785/46	1135/44	1320/49	1839/39	2038/37	2006/36	1773/36	1390/38	951/41	516/55	413/56
Sault Ste. Marie	46.5°	325/63	603/54	1028/45	1382/45	1687/44	1810/44	1834/41	1522/44	1049/50	673/54	331/66	253/66
Traverse City	44.7°	311/67	567/58	1000/48	1404/46	1728/44	1911/40	1908/39	1608/41	1165/46	754/51	377/64	256/69
MINNESOTA													
Duluth	46.8°	388/55	673/47	1034/45	1372/46	1631/46	1766/45	1853/40	1546/42	1095/48	725/50	380/59	291/60
Internat'l Falls	48.6°	356/54	662/45	1045/41	1442/41	1715/42	1852/42	1920/38	1618/39	1121/45	704/49	345/60	271/58
Minn.-St. Paul	44.9°	464/50	763/45	1102/44	1440/44	1736/42	1927/40	1969/37	1686/39	1254/42	859/44	480/54	353/57
Rochester	43.9°	476/51	752/47	1081/46	1409/46	1694/45	1900/41	1907/39	1661/40	1250/44	869/45	494/55	370/58
St. Cloud	45.6°	627/31	925/31	1349/29	1559/39	1839/39	1994/38	2046/34	1810/33	1327/38	888/41	538/47	453/44
MISSISSIPPI													
Jackson	32.3°	753/51	1026/46	1368/42	1707/39	1940/37	2023/37	1907/39	1780/39	1508/40	1271/38	901/45	708/44
Meridian	32.3°	743/51	1012/47	1327/44	1661/41	1859/40	1961/39	1822/41	1738/40	1453/44	1257/38	896/45	699/51
MISSOURI													
Columbia	39.0°	612/50	874/47	1178/46	1525/44	1878/39	2088/36	2114/32	1876/33	1449/38	1100/38	703/47	522/53
Kansas City	39.3°	647/47	894/45	1202/44	1574/41	1871/39	2078/36	2104/33	1862/34	1451/38	1092/38	737/44	561/49
St. Louis	38.7°	627/49	885/46	1204/45	1563/42	1870/39	2091/36	2048/34	1816/36	1458/38	1099/39	718/46	530/53
Springfield	37.2°	683/48	925/46	1235/45	1603/41	1881/39	2074/36	2061/34	1872/34	1479/38	1143/38	775/45	602/49
MONTANA													
Billings	45.8°	486/46	763/42	1189/38	1525/40	1912/37	2172/32	2382/23	2021/25	1469/31	986/33	561/44	421/47
Dillon	45.2°	526/44	845/37	1279/33	1638/36	1988/34	2142/33	2391/23	2022/25	1520/29	1022/32	601/41	450/45
Glasgow	48.2°	387/50	671/45	1104/39	1487/40	1826/39	2046/37	2192/29	1862/30	1339/34	877/37	478/46	333/50
Great Falls	47.5°	420/49	719/42	1169/37	1487/40	1847/38	2100/34	2327/25	1932/28	1377/33	924/34	498/46	335/53
Helena	46.6°	419/51	708/45	1145/39	1486/41	1859/38	2038/37	2333/25	1929/29	1412/33	925/37	521/46	364/51
Lewiston	47.0°	420/50	692/46	1128/39	1443/42	1806/40	2058/36	2286/27	1900/30	1371/34	904/37	502/47	363/50
Miles City	46.4°	457/47	745/42	1184/37	1541/39	1894/37	2144/33	2296/27	1976/27	1443/31	960/34	550/44	399/47
Missoula	46.9°	312/63	574/55	981/47	1382/45	1781/41	1932/40	2326/25	1880/30	1357/36	812/44	409/57	267/64
Summit	48.3°	450/42	597/50	988/45	1526/38	1703/44	1817/44	2065/33	1880/30	1305/36	796/42	376/57	280/58
NEBRASKA													
Grand Island	41.0°	660/41	917/40	1264/39	1692/37	1971/36	2241/30	2214/29	1938/31	1508/34	1137/33	738/40	569/44
Lincoln	40.8°	700/38	940/39	1279/39	1563/41	1829/40	2009/38	1979/37	1873/33	1519/33	1198/30	763/38	634/38
North Omaha	41.4°	633/42	891/41	1221/41	1558/41	1871/39	2121/34	2105/33	1857/33	1372/40	1049/38	644/47	511/49
North Platte	41.1°	692/38	958/38	1332/36	1723/34	1987/34	2265/30	2275/28	1988/24	1564/31	1176/30	759/38	605/40
Scotts Bluff	41.9°	675/38	950/37	1307/37	1667/37	1932/37	2235/31	2282/28	1998/29	1598/29	1145/31	723/39	575/41
NEVADA													
Elko	40.8°	689/39	1034/33	1462/30	1898/29	2302/24	2532/21	2621/16	2314/18	1891/18	1322/22	812/34	616/40
Ely	39.3°	819/32	1140/30	1605/25	2008/25	2309/24	2511/22	2445/22	2229/21	1934/19	1407/21	925/29	722/34

Appendix B | INSOLATION AND PERCENT DIFFUSE TABLES, CONTINUED | BTU per sq. ft. per day / % DIFFUSE

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Las Vegas	39.1°	977/28	1338/23	1822/19	2318/15	2644/14	2776/13	2587/18	2353/18	2036/16	1538/19	1085/25	880/30
Lovelock	40.1°	803/31	1165/27	1655/22	2164/19	2553/16	2747/15	2782/12	2482/12	2026/12	1450/16	929/27	714/32
Reno	39.5°	800/33	1149/29	1648/23	2158/20	2521/18	2700/16	2690/14	2404/15	1996/14	1430/19	911/30	705/34
Tonopah	38.1°	918/28	1273/23	1776/19	2250/18	2576/16	2786/13	2701/14	2437/14	2041/14	1520/16	1030/24	826/29
Winnemucca	40.9°	690/39	1027/33	1471/30	1966/25	2360/23	2568/20	2676/14	2347/16	1906/16	1321/22	809/34	618/39
NEW HAMPSHIRE													
Concord	43.2°	459/55	686/53	973/51	1316/49	1581/48	1704/47	1673/47	1455/47	1139/48	816/49	462/58	362/60
NEW JERSEY													
Atlantic City	39.4°	652/46	940/41	1419/33	1593/40	1817/41	2112/34	2094/33	1758/38	1445/38	1103/37	778/40	586/46
Lakehurst	40.0°	559/53	796/49	1108/48	1455/46	1671/46	1773/45	1702/46	1531/46	1260/46	955/45	621/51	475/55
Newark	40.7°	551/51	793/49	1108/47	1448/46	1686/45	1794/45	1758/44	1564/45	1272/45	950/45	596/51	454/56
Trenton	40.2°	638/45	900/42	1264/40	1563/41	1810/41	2013/38	1991/37	1729/39	1434/38	1084/38	719/42	571/46
NEW MEXICO													
Albuquerque	35.0°	1016/28	1341/25	1766/23	2227/20	2537/18	2677/16	2487/21	2289/21	1971/20	1545/20	1133/24	1927/29
Farmington	36.7°	944/29	1280/25	1692/24	2132/22	2450/21	2664/18	2477/21	2251/21	1933/20	1478/21	1046/27	837/31
Roswell	33.4°	1046/30	1372/27	1806/23	2216/21	2458/21	2608/19	2439/22	2240/23	1912/23	1526/23	1131/28	951/31
Zuni	35.1°	985/30	1296/28	1686/27	2165/22	2472/20	2600/19	2263/28	2077/28	1893/23	1495/23	1087/28	892/31
NEW YORK													
Albany	42.7°	502/53	766/48	1104/46	1493/42	1760/42	1950/39	1957/37	1699/39	1316/41	918/44	525/54	399/57
Binghamton	42.2°	386/64	575/62	860/58	1241/53	1493/51	1680/48	1658/47	1424/49	1131/49	778/53	414/65	297/68
Buffalo	42.9°	349/66	546/63	888/56	1314/49	1596/48	1806/44	1776/44	1512/46	1151/48	784/51	403/64	284/69
Ithaca	42.4°	450/57	748/49	1040/49	1283/51	1729/44	1987/38	1972/37	1696/39	1312/41	914/45	461/60	365/62
Massena	44.9°	431/54	692/49	1095/44	1500/41	1808/40	2006/38	1987/37	1687/38	1267/41	830/46	448/57	330/60
New York	40.8°	500/56	720/54	1036/50	1363/49	1635/47	1709/47	1686/46	1482/47	1213/47	895/48	533/57	403/60
Rochester	43.1°	364/65	569/62	903/55	1338/48	1605/47	1816/44	1780/44	1518/45	1159/48	781/51	403/64	281/69
Schenectady	42.8°	479/54	741/49	1010/50	1253/51	1526/50	1655/49	1637/48	1471/47	1106/50	807/50	476/58	383/58
Syracuse	43.1°	385/63	571/60	890/56	1323/49	1577/48	1777/45	1757/44	1502/46	1165/48	777/51	398/65	285/68
NORTH CAROLINA													
Asheville	35.4°	721/48	970/46	1305/42	1660/40	1803/41	1854/42	1775/44	1626/44	1360/45	1146/40	848/42	657/49
Cape Hatteras	35.3°	685/51	952/47	1325/41	1773/36	1960/37	2035/37	1919/39	1705/41	1470/40	1136/41	873/41	659/49
Charlotte	35.2°	719/49	970/46	1314/42	1694/39	1854/40	1920/40	1830/41	1694/41	1415/42	1173/39	865/42	672/50
Cherry Point	34.9°	756/47	1024/44	1386/39	1793/36	1923/38	1937/39	1828/41	1633/44	1433/42	1169/40	906/40	718/45
Greensboro	36.1°	715/47	969/45	1312/41	1682/39	1867/39	1952/39	1862/40	1695/41	1417/41	1140/40	838/42	658/47
Raleigh	35.8°	693/49	942/47	1275/44	1643/40	1807/41	1863/42	1774/44	1610/44	1376/44	1104/42	812/45	635/49
Raleigh-Durham	35.9°	793/42	1043/41	1379/39	1780/36	1905/38	1976/39	2038/36	1773/38	1463/40	1165/39	885/39	719/42
NORTH DAKOTA													
Bismarck	46.8°	467/46	775/39	1168/38	1458/42	1847/39	2059/36	2182/30	1876/31	1353/36	907/38	507/47	372/49
Fargo	46.9°	415/51	705/45	1097/41	1475/41	1833/39	1993/38	2119/32	1824/32	1303/38	874/39	457/51	337/54
Minot	48.2°	383/51	655/46	1043/42	1460/41	1845/38	1973/39	2097/32	1799/32	1276/38	849/39	439/50	310/54
OHIO													
Akron	40.9°	428/62	649/58	963/54	1356/49	1667/46	1838/44	1786/44	1595/44	1271/45	907/47	505/59	353/65
Cleveland	41.4°	388/65	601/60	922/56	1349/49	1680/45	1842/42	1826/41	1581/44	1239/46	866/48	466/62	318/68
Columbus	40.0°	459/60	676/57	979/54	1352/49	1646/49	1811/44	1754/45	1640/42	1279/45	949/46	537/57	387/64
Dayton	39.9°	489/58	725/55	1025/51	1402/48	1699/45	1872/42	1809/42	1644/41	1317/44	969/45	564/56	407/62
Put-in-Bay	41.6°	442/58	734/51	1077/48	1360/48	1821/40	1998/38	2090/33	1902/32	1471/34	1087/34	579/51	409/58
Toledo	41.6°	435/60	680/55	996/51	1383/48	1715/44	1877/41	1848/41	1615/42	1275/44	910/46	498/58	355/64
Youngstown	41.3°	385/65	586/62	889/57	1278/51	1585/48	1758/46	1733/45	1506/46	1193/48	851/49	456/63	315/68
OKLAHOMA													
Oklahoma City	35.4°	800/42	1054/41	1399/38	1724/38	1917/38	2142/33	2127/32	1949/32	1553/37	1232/36	901/39	725/44
Stillwater	36.1°	763/44	1054/40	1430/37	1681/39	1851/40	2186/32	2186/30	1998/30	1677/31	1268/31	947/34	752/40
Tulsa	36.2°	731/46	977/45	1305/42	1602/41	1821/41	2019/37	2029/36	1864/34	1471/39	1163/39	827/42	659/47
OREGON													
Astoria	46.2°	314/64	545/58	866/54	1252/50	1607/47	1625/49	1745/44	1498/45	1183/45	712/51	387/60	261/66
Burns	43.6°	490/51	792/45	1186/40	1648/37	2051/32	2278/29	2459/21	2082/24	1619/27	1042/34	593/46	431/51
Corvallis	44.5°	500/48	738/47	1027/47	1397/46	1671/45	1836/44	1770/44	1633/40	1310/40	989/36	588/45	432/49
Medford	42.4°	407/62	737/50	1132/45	1638/38	2032/33	2276/29	2473/21	2120/24	1588/29	981/40	504/56	336/65
North Bend	43.4°	439/57	704/50	1058/47	1508/42	1856/39	1993/38	2106/32	1785/36	1376/38	892/44	524/53	380/58
Pendleton	45.7°	348/62	613/54	1043/46	1501/41	1924/37	2143/33	2394/23	1993/27	1501/30	908/39	438/56	292/63
Portland	45.6°	310/66	554/58	895/54	1307/49	1662/45	1772/45	2036/34	1672/39	1216/44	723/51	387/62	260/67
Redmond	44.3°	490/49	774/45	1190/39	1682/34	2078/31	2286/29	2444/22	2068/24	1583/28	999/36	571/47	424/50
Salem	44.9°	332/65	587/57	947/51	1369/47	1796/42	1847/42	2141/31	1773/36	1328/39	769/50	410/60	277/66
PENNSYLVANIA													
Allentown	40.6°	527/54	763/51	1078/48	1409/47	1636/47	1776/45	1764/44	1545/45	1237/46	925/46	568/54	430/58
Avoca	41.3°	454/59	688/55	991/53	1338/49	1589/48	1758/46	1744/45	1512/46	1198/47	896/47	490/59	368/63
Erie	42.1°	345/68	577/62	919/55	1358/48	1645/46	1846/42	1832/41	1454/48	1200/47	827/50	416/65	277/71
Harrisburg	40.2°	535/54	770/51	1082/49	1410/47	1651/46	1803/44	1762/44	1550/45	1265/45	933/46	579/54	447/57
Philadelphia	39.9°	555/53	794/50	1108/48	1433/47	1659/46	1810/44	1757/44	1574/45	1280/45	958/45	619/51	470/56
Pittsburgh	40.5°	424/62	625/60	942/53	1316/50	1601/48	1761/46	1689/46	1510/46	1208/48	895/48	504/59	346/66
State College	40.8°	512/55	745/51	1095/48	1375/48	1721/44	2006/38	1947/38	1674/40	1331/42	1014/40	571/54	442/57
RHODE ISLAND													
Newport	41.5°	571/48	852/44	1217/41	1456/45	1803/41	1983/39	1817/39	1655/41	1401/38	1006/40	645/46	520/48
Providence	41.7°	506/54	738/51	1031/50	1373/48	1654/46	1774/45	1694/46	1498/47	1208/47	906/46	537/55	418/57
SOUTH CAROLINA													
Charleston	32.9°	744/50	995/47	1338/44	1731/38	1859/40	1843/42	1798/42	1584/46	1393/45	1192/41	933/41	720/48
Columbia	33.9°	761/48	1020/45	1354/41	1745/37	1893/39	1946/39	1840/41	1701/41	1438/42	1211/39	920/40	721/47
Grnvle.-Sptnbrg	34.9°	729/49	981/46	1328/41	1697/39	1838/39	1918/39	1830/40	1699/40	1405/42	1180/34	880/40	670/49
SOUTH DAKOTA													
Huron	44.4°	488/49	744/47	1113/44	1529/40	1870/38	2100/34	2181/30	1891/31	1417/34	988/37	577/46	405/53
Pierre	44.4°	529/45	794/42	1205/38	1613/38	1965/36	2193/32	2277/27	1991/28	1495/31	1051/32	623/41	442/48

City	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rapid City	44.1°	542/45	826/41	1228/38	1588/38	1885/38	2130/33	2222/29	1961/29	1517/31	1063/32	646/40	476/45
Sioux Falls	43.6°	532/47	801/44	1152/42	1542/40	1892/38	2098/34	2149/31	1843/33	1409/36	1005/37	607/45	441/50
TENNESSEE													
Chattanooga	35.0°	630/53	858/53	1176/48	1549/44	1730/44	1830/42	1734/45	1629/44	1335/46	1108/42	772/48	580/55
Memphis	35.0°	682/51	944/48	1277/44	1638/41	1884/39	2043/37	1971/37	1823/37	1470/40	1204/38	816/46	628/51
Nashville	36.0°	601/65	882/59	1188/56	1638/49	1911/46	2081/43	2033/43	1845/44	1561/44	1199/46	808/57	605/60
Oak Ridge	36.0°	612/55	877/50	1202/47	1648/40	1898/38	2009/38	1921/39	1755/39	1537/37	1176/38	778/47	593/53
TEXAS													
Abilene	32.4°	923/40	1182/38	1575/33	1842/34	2036/34	2208/31	2138/32	1955/32	1596/37	1313/36	1007/38	863/39
Amarillo	35.2°	960/31	1242/31	1630/29	2017/27	2210/29	2392/25	2279/28	2102/27	1759/28	1403/28	1032/31	871/32
Big Spring	32.2°	988/36	1268/33	1718/28	2126/23	2109/32	2186/31	2035/34	1725/41	1928/23	1423/30	1073/33	958/33
Brownsville	25.9°	912/50	1135/47	1456/42	1736/40	1926/38	2114/32	2211/29	2026/31	1692/37	1438/37	1054/45	862/50
Corpus Christi	27.8°	897/48	1146/45	1437/42	1641/42	1865/39	2092/33	2184/30	1989/32	1686/36	1415/36	1072/42	844/48
Dallas	32.8°	821/46	1071/44	1421/40	1626/42	1887/39	2134/33	2120/32	1949/33	1586/37	1275/37	936/41	779/45
El Paso	31.8°	1124/28	1479/23	1908/20	2362/16	2599/16	2680/16	2449/22	2283/22	1986/22	1638/21	1243/24	1030/29
Fort Worth	32.8°	800/47	1063/44	1401/40	1610/42	1882/39	2145/33	2146/31	1972/32	1610/36	1276/37	926/42	757/46
Houston	30.0°	772/53	1034/48	1296/47	1522/47	1773/42	1897/40	1827/41	1685/42	1470/42	1275/40	924/47	729/53
Kingsville	27.5°	911/48	1161/45	1434/42	1662/42	1863/39	2035/36	2110/32	1921/34	1624/38	1389/37	1034/44	849/48
Lubbock	33.6°	1030/30	1331/29	1761/24	2166/22	2394/22	2543/21	2410/23	2207/24	1819/27	1467/27	1116/29	934/31
Lufkin	31.2°	793/50	1068/46	1375/42	1623/42	1865/40	2054/36	2005/36	1862/36	1529/40	1348/36	962/42	767/48
Midland	31.9°	1080/30	1382/29	1838/23	2191/22	2429/21	2561/20	2388/23	2208/24	1843/28	1521/27	1176/28	999/31
Port Arthur	29.9°	800/51	1070/47	1353/45	1609/44	1869/39	2009/37	1845/41	1735/41	1526/41	1321/38	952/45	754/51
San Angelo	31.4°	961/39	1207/38	1605/33	1849/34	2030/34	2185/31	2121/32	1965/32	1606/37	1336/36	1043/37	894/39
San Antonio	29.5°	895/46	1154/44	1449/41	1611/44	1893/39	2068/34	2120/32	1946/33	1634/37	1349/37	1008/42	846/46
Waco	31.6°	832/47	1095/44	1427/40	1611/42	1773/42	2111/33	2129/32	1957/33	1600/37	1301/37	956/42	802/45
Wichita Falls	34.0°	861/41	1122/39	1471/37	1762/37	2016/34	2220/31	2165/31	1968/32	1601/36	1291/34	956/38	799/41
UTAH													
Cedar City	37.7°	881/31	1179/30	1634/25	2091/23	2466/20	2704/16	2502/20	2240/21	1967/18	1459/21	992/28	785/33
Salt Lake City	40.8°	638/44	988/37	1453/30	1893/29	2361/23	2559/21	2588/18	2252/20	1842/20	1293/24	787/36	570/45
VERMONT													
Burlington	44.5°	425/56	678/51	1055/46	1449/44	1766/41	1949/39	1950/38	1672/39	1264/42	834/46	433/59	320/63
VIRGINIA													
Mt. Weather	39.1°	634/48	1010/38	1246/42	1526/44	1873/39	1935/40	1880/40	1585/44	1382/42	1036/41	745/44	619/44
Norfolk	36.9°	678/49	932/46	1280/42	1676/39	1886/39	1999/38	1852/41	1679/41	1395/41	1082/41	811/41	623/48
Richmond	37.8°	631/50	876/48	1210/45	1565/42	1761/42	1871/42	1773/44	1599/44	1347/44	1032/44	733/47	566/51
Roanoke	37.3°	660/49	899/47	1235/45	1581/42	1763/42	1881/41	1795/42	1619/44	1357/44	1080/41	764/45	590/50
WASHINGTON													
Olympia	47.0°	269/68	503/60	844/55	1255/50	1631/46	1692/47	1912/39	1548/42	1156/45	636/56	339/64	221/69
Prosser	46.2°	431/50	818/37	1294/31	1921/24	2271/24	2507/22	2606/16	2227/18	1689/20	1010/31	501/48	369/51
Pullman	46.7°	453/47	671/48	1095/41	1681/33	1998/33	2529/21	2603/16	2035/24	1578/24	944/34	542/44	354/53
Richland	46.3°	317/64	741/44	1228/34	1721/32	1902/37	2385/25	2124/32	2216/19	1430/32	844/42	457/53	365/53
Seattle	47.4°	288/65	501/59	973/47	1460/41	1847/38	1921/40	2090/32	1685/38	1209/41	697/51	391/57	236/67
Spokane	47.7°	314/62	606/51	1040/44	1494/40	1917/36	2082/36	2355/24	1941/28	1434/31	840/40	397/56	255/64
Tacoma	47.2°	262/68	495/60	849/54	1293/48	1713/42	1801/44	2246/28	1615/40	1146/45	656/54	337/64	211/71
Whidbey Is.	48.3°	293/65	532/55	917/50	1345/45	1760/40	1820/45	1981/35	1592/40	1173/40	655/53	357/60	233/67
WEST VIRGINIA													
Charleston	38.4°	498/60	706/57	1009/54	1355/50	1639/47	1774/45	1682/47	1514/47	1272/46	971/46	613/55	440/62
Parkersburg	39.3°	527/56	745/54	1113/48	1397/48	1795/41	1994/38	1939/38	1784/37	1453/38	1047/41	616/53	487/56
WISCONSIN													
Eau Claire	44.9°	452/53	746/46	1089/44	1425/45	1680/45	1870/42	1885/40	1619/41	1196/45	826/46	450/57	341/59
Green Bay	44.5°	451/53	725/48	1103/44	1438/44	1718/44	1906/41	1887/39	1621/41	1217/44	820/47	465/56	350/59
La Crosse	43.9°	481/51	764/46	1100/45	1426/45	1712/44	1904/41	1899/39	1665/40	1242/44	893/46	494/55	369/58
Madison	43.1°	515/50	803/45	1135/44	1397/46	1742/42	1947/40	1933/38	1707/38	1299/41	910/44	504/55	388/57
Milwaukee	42.9°	479/54	736/49	1088/46	1441/45	1767/42	1976/39	1960/38	1718/38	1309/41	907/44	524/54	378/59
WYOMING													
Casper	42.9°	682/34	1013/30	1441/29	1846/29	2202/28	2500/22	2533/19	2224/20	1749/21	1218/24	764/32	593/36
Cheyenne	41.1°	765/31	1067/30	1432/31	1769/33	1994/34	2257/30	2229/29	1965/30	1666/27	1241/27	822/32	671/33
Lander	42.8°	848/19	1183/19	1662/18	2038/22	2156/29	2488/23	2389/23	2138/23	1711/23	1312/19	874/23	726/22
Laramie	41.3°	826/25	1099/28	1563/24	1836/31	2020/33	2311/29	2186/30	1939/31	1548/32	1176/30	837/31	675/32
Rock Springs	41.6°	734/33	1088/28	1530/25	1943/27	2343/23	2573/20	2546/19	2238/20	1832/19	1305/22	826/31	650/34
Sheridan	44.8°	517/45	787/42	1204/38	1537/40	1882/38	2155/33	2327/25	2005/27	1500/31	1005/34	590/44	441/47
ALBERTA													
Edmonton	53.6°	328/39	649/32	1150/28	1522/34	1876/36	1891/41	1939/37	1508/41	1099/40	693/39	409/36	245/44
Lethbridge	49.6°	442/38	774/32	1253/29	1548/37	1917/36	2138/33	2249/28	1917/28	1364/31	885/33	516/37	332/46
BRITISH COLUMBIA													
Vancouver	49.0°	280/63	383/67	689/62	1264/48	1725/42	1777/45	2009/36	1467/45	929/54	590/56	350/58	206/67
MANITOBA													
Churchill	58.7°	240/23	553/23	1124/18	1640/24	1880/33	1954/38	1862/38	1401/42	829/49	424/53	221/45	129/42
Winnipeg	49.9°	483/31	829/27	1338/23	1618/33	1880/37	1935/40	2094/32	1740/34	1179/41	756/42	439/46	339/44
NEW BRUNSWICK													
Moncton	46.1°	369/58	664/51	1069/44	1401/45	1622/46	1659/48	1733/45	1512/45	1143/46	774/48	405/58	332/57
NEWFOUNDLAND													
St. Johns	47.5°	295/64	553/56	885/51	1180/53	1475/50	1585/50	1622/48	1253/54	1032/50	627/56	295/67	258/64
ONTARIO													
Ottawa	45.4°	531/42	841/37	1235/36	1486/41	1832/39	2057/36	2016/36	1729/37	1309/39	815/46	453/55	402/50
Sapuskasing	49.4°	405/45	700/39	1143/34	1364/45	1512/49	1770/45	1770/42	1475/45	995/50	590/56	295/64	295/53
Toronto	43.7°	446/55	682/51	1077/46	1372/47	1762/42	1917/40	1943/38	1600/42	1268/42	826/48	453/58	350/60
QUEBEC													
Montreal	45.5°	405/56	737/45	1180/38	1435/42	1733/42	1806/44	1880/40	1622/40	1143/47	737/51	369/64	295/63

Appendix C

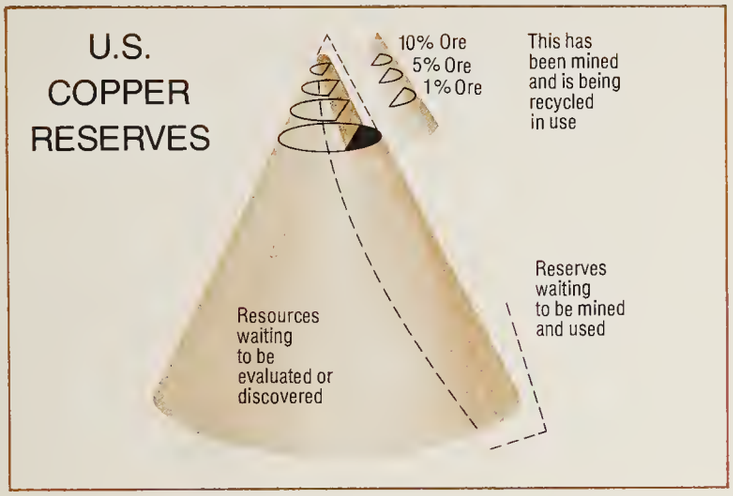
TABLE 12/COLLECTOR TILT FACTORS

		LATITUDE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
20% Diffuse	COLLECTOR TILT = LAT. − 15°	24°	1.13	1.09	1.04	1.00	0.97	0.96	0.97	1.00	1.04	1.10	1.12	1.15
		32°	1.34	1.24	1.11	0.99	0.93	0.94	0.92	0.98	1.11	1.28	1.34	1.42
		40°	1.67	1.41	1.23	1.01	0.90	0.90	0.89	1.02	1.21	1.42	1.73	1.76
		48°	2.18	1.64	1.51	1.10	0.96	0.80	0.95	1.08	1.43	1.73	2.26	2.56
	COLLECTOR TILT = LATITUDE	24°	1.31	1.21	1.08	0.95	0.87	0.85	0.87	0.94	1.08	1.21	1.28	1.37
		32°	1.56	1.39	1.16	0.97	0.79	0.76	0.78	0.96	1.15	1.45	1.56	1.71
		40°	1.95	1.55	1.28	0.98	0.75	0.75	0.74	1.00	1.25	1.57	2.05	2.10
		48°	2.53	1.80	1.57	1.08	0.90	0.74	0.89	1.05	1.49	1.90	2.63	3.04
	COLLECTOR TILT = LAT. + 15°	24°	1.40	1.25	1.06	0.80	0.70	0.67	0.70	0.79	1.05	1.27	1.36	1.50
		32°	1.69	1.45	1.13	0.89	0.59	0.55	0.58	0.88	1.12	1.54	1.68	1.89
		40°	2.11	1.60	1.25	0.91	0.67	0.65	0.66	0.92	1.23	1.63	2.24	2.30
		48°	2.72	1.85	1.54	1.00	0.79	0.65	0.78	0.97	1.45	1.98	2.84	3.34
40% Diffuse	COLLECTOR TILT = LAT. − 15°	24°	1.10	1.07	1.03	1.00	0.97	0.96	0.97	1.00	1.03	1.07	1.09	1.12
		32°	1.27	1.20	1.09	0.98	0.93	0.95	0.92	0.97	1.09	1.22	1.26	1.33
		40°	1.52	1.33	1.18	0.98	0.89	0.89	0.89	1.00	1.16	1.34	1.59	1.61
		48°	1.93	1.50	1.42	1.06	0.94	0.78	0.93	1.04	1.35	1.57	2.02	2.23
	COLLECTOR TILT = LATITUDE	24°	1.24	1.16	1.06	0.95	0.88	0.86	0.88	0.94	1.05	1.17	1.21	1.28
		32°	1.44	1.31	1.12	0.96	0.79	0.76	0.78	0.95	1.11	1.36	1.43	1.56
		40°	1.74	1.44	1.21	0.96	0.74	0.74	0.73	0.97	1.19	1.46	1.84	1.87
		48°	2.20	1.61	1.45	1.03	0.88	0.73	0.87	1.01	1.38	1.71	2.31	2.60
	COLLECTOR TILT = LAT. + 15	24°	1.32	1.19	1.03	0.80	0.72	0.69	0.72	0.79	1.03	1.20	1.26	1.38
		32°	1.53	1.36	1.09	0.89	0.59	0.56	0.58	0.88	1.08	1.42	1.52	1.70
		40°	1.85	1.47	1.18	0.88	0.67	0.66	0.66	0.90	1.15	1.50	1.98	2.03
		48°	2.34	1.64	1.41	0.95	0.78	0.64	0.77	0.93	1.34	1.75	2.46	2.82
60% Diffuse	COLLECTOR TILT = LAT. − 15°	24°	1.07	1.05	1.02	1.00	0.98	0.97	0.98	0.99	1.02	1.05	1.06	1.09
		32°	1.20	1.15	1.06	0.97	0.93	0.95	0.92	0.96	1.06	1.17	1.19	1.25
		40°	1.38	1.25	1.13	0.96	0.88	0.89	0.88	0.98	1.12	1.26	1.45	1.46
		48°	1.69	1.35	1.33	1.02	0.92	0.77	0.91	1.00	1.27	1.42	1.77	1.90
	COLLECTOR TILT = LATITUDE	24°	1.17	1.11	1.04	0.94	0.89	0.87	0.89	0.93	1.03	1.12	1.13	1.20
		32°	1.31	1.24	1.07	0.94	0.79	0.76	0.78	0.94	1.07	1.26	1.30	1.41
		40°	1.53	1.32	1.14	0.93	0.73	0.74	0.73	0.95	1.12	1.35	1.63	1.65
		48°	1.87	1.42	1.34	0.99	0.86	0.72	0.85	0.97	1.28	1.51	1.98	2.16
	COLLECTOR TILT = LAT. + 15°	24°	1.22	1.13	1.00	0.80	0.73	0.71	0.73	0.79	1.00	1.13	1.16	1.25
		32°	1.37	1.26	1.04	0.88	0.59	0.56	0.58	0.87	1.03	1.30	1.36	1.50
		40°	1.60	1.34	1.10	0.86	0.66	0.66	0.66	0.88	1.08	1.37	1.72	1.76
		48°	1.96	1.43	1.29	0.91	0.77	0.64	0.76	0.89	1.23	1.52	2.09	2.31
80% Diffuse	COLLECTOR TILT = LAT. − 15°	24°	1.04	1.03	1.01	1.00	0.98	0.97	0.98	0.99	1.01	1.03	1.04	1.05
		32°	1.12	1.11	1.04	0.96	0.93	0.96	0.92	0.96	1.04	1.11	1.12	1.16
		40°	1.24	1.17	1.08	0.94	0.88	0.88	0.87	0.96	1.07	1.18	1.30	1.31
		48°	1.44	1.22	1.24	0.98	0.90	0.75	0.89	0.97	1.19	1.27	1.53	1.57
	COLLECTOR TILT = LATITUDE	24°	1.10	1.07	1.01	0.94	0.90	0.89	0.90	0.93	1.01	1.07	1.06	1.11
		32°	1.19	1.16	1.03	0.93	0.79	0.77	0.78	0.93	1.03	1.17	1.18	1.26
		40°	1.33	1.21	1.07	0.90	0.73	0.74	0.72	0.93	1.06	1.23	1.42	1.43
		48°	1.55	1.25	1.22	0.94	0.84	0.70	0.84	0.93	1.18	1.31	1.66	1.72
	COLLECTOR TILT = LAT. + 15°	24°	1.12	1.06	0.98	0.80	0.75	0.73	0.75	0.79	0.97	1.06	1.05	1.13
		32°	1.21	1.17	0.99	0.87	0.60	0.57	0.59	0.86	0.99	1.18	1.19	1.31
		40°	1.35	1.20	1.02	0.83	0.66	0.66	0.65	0.86	1.01	1.24	1.47	1.49
		48°	1.58	1.23	1.16	0.87	0.76	0.63	0.75	0.85	1.12	1.29	1.71	1.79

COPPER FACTS Supply • Sources • Energy

The future is bright for tomorrow's supply of copper. Copper is plentiful in the United States. Natural abundance plus recycling make the nation essentially self-sufficient in copper. Moreover, copper's production is energy efficient.

Visualize the copper on earth as a cone of resources. Up to now man has found, extracted and put into recycling use a slice off the tip of that cone. Below that slice are the



known reserves of copper waiting to be mined and used. Behind those reserves are the rest of the earth's copper resources, known to exist but which may not yet be precisely located or economically or legally recoverable. The most recent Bureau of Mines estimate is: copper in U.S. ore reserves, 202 billion pounds; copper in additional U.S. ore resources, 640 billion pounds. This total of 842 billion pounds of U.S. copper resources is about 250 times current annual U.S. requirements, which have averaged 3.2 billion pounds in the 1970's.

In addition to the plentiful supply of new copper, there is another naturally occurring copper resource that no other metal can match: ease of recycling. Today, almost half the copper in U.S. mill and foundry products comes from recycled scrap. During the 1970's, an average of 3.2 billion pounds came from newly-mined ore each year and 2.8 billion pounds (47% of total copper production) from U.S. scrap resources.

Although copper is mined around the world, the U.S. is essentially self-sufficient in copper. During the 1970's, the U.S. averaged nearly 92% in net total copper and copper alloy self-sufficiency, with a high of 97% reached in 1970 and again in 1975. No other engineering metal can make such a claim.

Copper is favorably situated among the metals when it comes to "energy cost." Based on mid-seventies technology, the production of copper from ore in the U.S. requires the equivalent of from 12.2 to 15.7 kilowatt hours per pound, depending on ore type and grade. This includes both direct energy usage and indirect energy requirements represented by equipment use and supplies consumed. It also includes losses due to the inefficiencies of energy conversion. Production from scrap is even more energy efficient.

It is interesting to calculate the energy cost of the material in a solar collector panel. That is, how much energy is required to produce from ore the metal in the fins and tubes that make up one square foot of absorber plate? The answer for copper is about 47,000 Btu. This means a copper collector installed in Tucson on January 1 can pay back its energy debt with useful heat by June 4 of the same year, based on data from an actual installation.

ENERGY COST OF METALS PRIMARY PRODUCTION

	kwh per pound
Carbon Steel	3.4
Lead	3.8
Cast Iron	4.8
Zinc	9.1
Copper	12.2—15.7
Nickel	20.2
Aluminum	34.2
Magnesium	50.1
Titanium	57.1

COPPER BENEFITS Properties and Advantages for Solar Energy Systems

The copper metals, copper, brass and bronze, are uniquely suited for solar heating systems. Without copper, the outlook for solar energy in the U.S.A. would be nowhere near so bright as it is today.

- **Thermal conductivity**—unsurpassed among engineering materials, the key to cost-effective solar collectors and heat exchangers.
- **Corrosion resistance**—both in hot water and in glycol-water solutions, proven by decades of successful service.
- **Joinability and Ease of Fabrication**—in the factory and in the field, unsurpassed for solar heating system components.
- **Familiarity**—in building construction and throughout the plumbing, heating and cooling industry.
- **Availability**—abundant supply in the U.S.A., half of it from recycled scrap, both energy efficient sources.

COPPER DEVELOPMENT ASSOCIATION INC.
405 LEXINGTON AVENUE, NEW YORK, N.Y. 10174

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MONTANA
SOLAR
HOT WATER

COMPARISON OF SOLAR COLLECTOR GLAZING MATERIALS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

COMPARISON OF SOLAR COLLECTOR GLAZING MATERIALS

Material	Typical Thickness (inches)	Percent Solar Transmission	Infrared Transmission	Maximum Temperature (°F)	Weight	Thermal Expansion	Remarks
Low Iron Tempered Glass	0.125 0.188	91.6 91.3	very low	400	heavy	low	Industry standard.
Polycar-bonate	0.040 0.144	81 85	very low	250	medium	high	Very strong. Not UV stable.
Acrylic	0.125 0.188	89 87	very low	190	medium	high	Not high strength. UV stable.
Fiberglass Reinforced Plyester (FRP)	0.040	88	low	225	light	medium	Not chemically and heat stable. Translucent.
Acrylic Polyester Film	0.007 0.011	91 89	low	275	very light	N/A	Very tough when laminated.
Polyvinyl Fluoride Film	0.004	90	medium	300	very light	N/A	Heat shrinkable. Lost cost outer glazing.
Fluor-carbon Film	0.001	96	high	400	very light	N/A	Very inert. Not mechanically strong. Good inner glazing.

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Capitol Station
Helena, MT 59620
Montana Department of
Natural Resources and Conservation

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MONTANA
SOLAR
HOT WATER

UNDERSTANDING SOLAR COLLECTOR PERFORMANCE GRAPHS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

UNDERSTANDING SOLAR COLLECTOR PERFORMANCE GRAPHS

The efficiency of any conversion device or process is the useful output divided by the input. There is no real device or process that converts energy from one form (electromagnetic) to another (thermal) or transfers energy from one place (solar collector) to another (storage tank) at 100% efficiency. Some of the energy input into the device or process will always be lost.

$$\text{EFFICIENCY} = \eta = \frac{\text{USEFUL ENERGY OUTPUT}}{\text{SOLAR ENERGY INPUT}} = \text{less than } 100\%$$

Efficiency is decreased as energy is lost. Generally, energy is lost and efficiency decreases as the "usefulness" of the output energy increases. Thus it is possible to convert sunshine to hot water at much higher efficiences than it is to convert sunlight to a more useful energy form such as electricity. This is why we use solar thermal conversions rather than solar electric conversions for low temperature space and water heating.

How Energy is Gained and Lost from a Solar Collector

I. Absorption

Only part of the energy incident on the solar collector can be absorbed. The ratio of the energy avialable to the energy absorbed is called the absorptance and is designated by the symbol α(alpha).

Real black surfaces generally cannot absorb more than 90% to 98% of the energy incident on them. The remaining energy is reflected and lost from the absorber. With no other losses from the absorber, the efficiency becomes:

$$\eta = \alpha = \frac{\text{absorbed radiation}}{\text{incident radiation}}$$

II. Heat Losses from the Absorber

There are other losses from the absorber. These losses include: the energy that is conducted away from the absorber to the external maniforlds or from the absorber to the collector frame; the energy that is convected away from the absorber to surrounding air; and the energy that is re-radiated from the absorber to the surroundings that exist at a lower surface temperature than the absorber. An assumption is made (albeit somewhat inaccurately), that all of these losses are proportional to the temperature difference between the absorber plate temperature (T_p) and the ambient air temperature (T_a). A constant is defined (U_L) so as to combine all of these effects in one term. This represents the overall heat loss coefficient of the absorber plate per unit area.

$$\left.\begin{matrix}\text{conduction} \\ + \\ \text{convection} \\ + \\ \text{radiation}\end{matrix}\right\} = \text{Losses} = U_L(T_p - T_a)$$

In order to obtain a more accurate estimate of the collector efficiency we subtract heat losses from the total amount of solar

absorbed and divide by the total insolation (Incident Solar Radiation) usually designated by I.

$$\eta = \alpha - U_L \frac{(T_p - T_a)}{I}$$

III. Adding Insulation and a Cover Plate

If the heat loss coefficient is large then the temperature difference, $(T_p - T_a)$ must be small in order to retain any useful fraction of the energy originally absorbed. However, most solar applications require that the collector absorber plate operate at temperatures significantly higher than the ambient air temperature. For example, in domestic water heating applications in Montana, collectors should operate at 140°F when the ambient temperature is 0°F (which is a difference of 140°F). On cloudy days when I is low then U_L will clearly have to be very low in order to retain any useful fraction of the energy absorbed.

It is possible to lower U_L by insulating the collector absorber. It is easy to frame the absorber and insulate the back and sides to limit the heat lost in those directions. The only material we can use to insulate the front of the collector must be transparent to allow the sunlight to be absorbed.

Just as there is no absorber that can absorb all of the energy available to it, there is no cover plate that is 100% transparent. Any real cover plate will reflect some of the sunlight incident on

it. This reflected light will not be available for absorption, so in our attempt to reduce U_L we cannot help but decrease the amount absorbed. The fraction of sunlight not reflected from the cover is called the transmission, symbolized by τ (tau), and defined as:

$$\text{Transmission} = \tau = \frac{\text{Transmitted energy}}{\text{Incident energy}}$$

Typical transmission values range from 0.8 to 0.95. If we can retain high transmission over time and expect to operate our collector at temperatures much above the ambient air temperatures then our trade off was a good one. The addition of insulation to the back and sides and a transparent cover plate for the collector front has reduced our overall heat loss to where we may operate at large temperature differences between the absorber and the outside air.

The cover plate cuts heat loss in two very important ways. Convection losses are cut by keeping the cold ambient air away from the hot absorber plate. Radiation losses are cut because of a unique ability of most glazing materials, (especially glass), to be transparent to short wave solar radiation while being mostly opaque to long wave thermal radiation (or infrared). Solar energy is converted to thermal energy upon striking the absorber plate and thus becomes trapped inside the collector. Since glass is only partially opaque to infrared, there are still radiation losses, but our addition of the cover plate has cut into these drastically. As we shall see there are other ways to cut radiation losses from the absorber besides glazing.

Now we can redefine absorption in light of the effectiveness of the cover plate at transmitting light. Since the fraction of light transmission through the cover plate is the cover transmission multiplied by the Insolation, then the total which can be absorbed must be:

$$\text{Absorbed Energy} = \tau\alpha I$$

(a fraction of a fraction of the total Insolation)

and

$$\frac{\text{Absorbed Energy}}{\text{Incident Energy}} = \tau\alpha$$

is called the "effective transmittance-absorptance product" and represents the total amount of energy available to the heat transfer fluid.

IV. Taking the Heat Away

Once energy has been transmitted and absorbed it must be made available to the heat transfer fluid which will move the heat out of the collector to a storage or distribution system.

In order to gain energy on a trip through the collector the heat transfer fluid must rise in temperature. This indicates that the temperature of the absorber must increase from the fluid inlet to the fluid outlet. Thus T_p can only be measured in small local areas of

the absorber. It is much more convenient to measure the inlet temperature of the collector T_i and use it in place of the plate temperature T_p. To do this and maintain accuracy, we must modify both the transmittance-absorptance product as well as the collector heat loss coefficient in a way that reflects the temperature rise across the absorber.

The temperature rise across the absorber is a function of absorber plate variables as well as system variables. The absorber plate construction is influenced by several factors:

1. The fluid path length;
2. The thickness of the absorber plate;
3. The conductivity of the absorber plate material
4. The conductivity of the joint between fin and tube;
5. The distance between tubes; and
6. The diameter or size of the tubes.

Factors influencing system design include the following:

1. The heat capacity of the transfer fluid;
2. The thermal conductivity of the transfer fluid; and
3. The fluid flowrate.

These system variables have little influence on the performance curve since all collectors are tested using water as the transfer fluid at specified flowrates. However, these variables do have a significant effect on the actual installed performance.

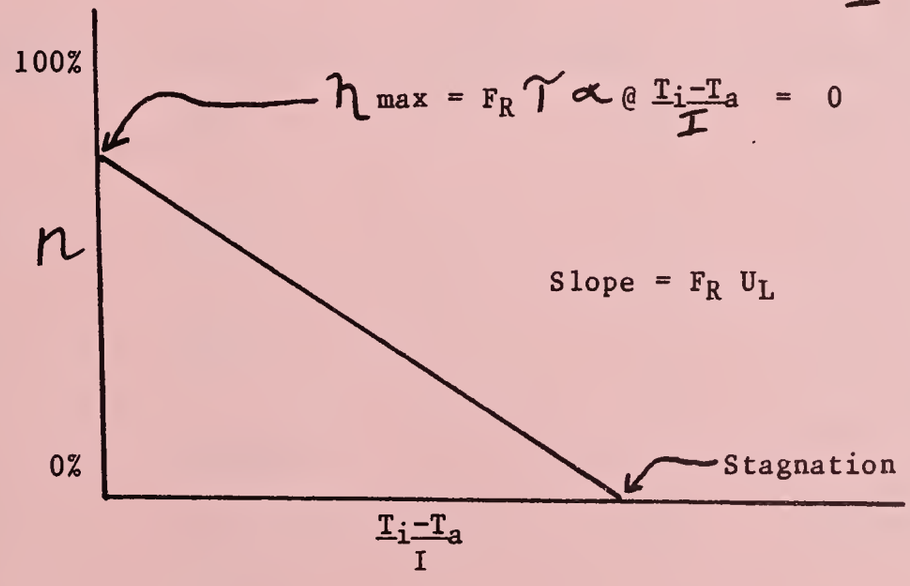
A correction factor, F_R, (the heat removal factor) has been defined that takes these system variables into account and allows one to relate T_p to T_i. This correction factor gets multiplied by both the effective transmittance-absorptance product as well as the collector heat loss coefficient to yield the final collector performance equation:

$$\eta = F_R \tau\alpha - F_R U_L \left(\frac{T_i - T_a}{I} \right)$$

The Performance Graph

The design of the collector fixes all of the variables except $\left(\frac{T_i - T_a}{I}\right)$ and, to some extent, F_R.

This allows us to graph the efficiency as a function of $\frac{T_i - T_a}{I}$.



The maximum efficiency occurs when $T_i = T_a$ and is $F_R \tau\alpha$. The line slopes at a rate that is equal to $F_R U_L$. The

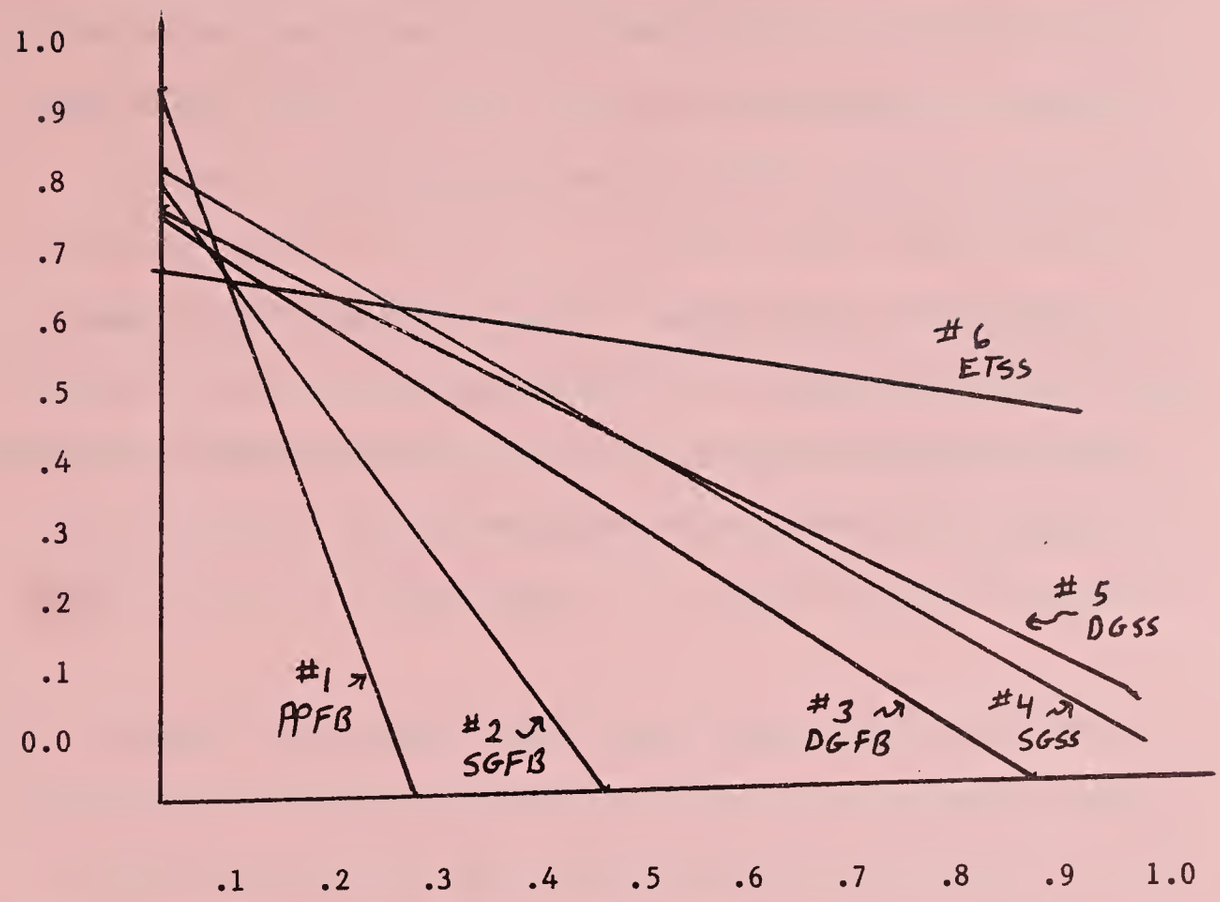
intersection of the line with the horizontal axis represents 0% efficiency and is the condition under which the collector energy gain equals the energy loss or:

$$\tau\alpha = U_L \frac{T_i - T_a}{I}$$

These are the conditions under which the collector produces no useful energy and is called stagnation. We can solve for the inlet temperature, T_i, at which this occurs by algebraically rearranging the equation to yield:

$$T_{stagnation} = I \frac{\tau\alpha}{U_L} + T_a$$

The stagnation temperature represents the maximum useful inlet temperature. This is the temperature at which the control should turn the system off.



#	# Glazings	Absorber	$F_R(\tau\alpha)$	$F_R U_L$	Description
1	None	Flat Black	.90	3.6	Pool Panel, Copper tube, aluminum fin
2	Single	Flat Black	.77	1.73	Flat Plate
3	Double	Flat Black	.74	.84	Flat Plate
4	Single	Selective Surface	.80	.78	Flat Plate
5	Double	Selective Surface	.72	.63	Flat Plate
6	Single	Selective	.66	.19	Evacuated tube, Compound Parabolic Cusp Reflector

While long-term predictions of system performance cannot be based entirely on performance curves, many design decisions can be made on information that the above graph makes available. The performance curves shown above are representative of several types of solar collectors and demonstrate the usefulness of the performance graphs to specify collectors for different applications.

Collector #1 is an unglazed collector normally used to heat seasonal outdoor pools. The lack of glazing allows the collector to reach very high efficiencies. It also causes the efficiency to fall off rapidly as the operating temperature increases since the collector loses heat before it is taken away.

Collector #2 is a more typical glazed flat plate collector. Both it and collector #3 have flat black coating applied to the absorber. No. 3 however has been double glazed which has reduced its F_R compared to #2 but has also reduced its heat loss. Collector #3 would be a good collector to run at high temperatures in cold weather but it is outdone by #4 which is single glazed and has a higher peak efficiency. How is this? Collector #4 has a selective surface of Black Chrome applied to its absorber. The selective surface cuts heat loss from the absorber by limiting the infrared radiation losses from the absorber at elevated temperatures. The selective surface is as effective at preventing heat losses as double glazing but does not cut into the light trnasmission as much. It should be noted that the solar industry has generally favored the use of selective surfaces rather than double glazing for high performance, low heat loss solar

collectors. Collector #4 not only exhibits lower heat loss than Collector #3, but has a peak efficiency 6% higher due to its higher light transmission through the single glazing.

Performance curve #5 shows that a collector which incorporates both double glazing as well as a selective surface barely has any performance advantages over collector #4 in terms of heat loss and suffers a much lower peak efficiency due to the double glass. Unless you are running very high temperatures in very cold weather, the extra weight and cost would probably be not worth any increase in performance over collector #4.

If one is to run high temperatures in cold and cloudy weather then Collector #6 is the collector of choice. Collector #6 is an evacuated tube collector that utilizes compound parabolic concentrators to help gather diffuse light. Because of the selective surface and the "thermos" bottle effect, the evacuated tube collector exhibits extremely low heat loss characteristics. The curves show that the ETC will exhibit higher performance than its closest competitor, #4, at all $\frac{T_i - T_a}{I}$ greater than .25. A collector such as this would be very competitive with flat plate at collectors generating 140°F hot water in any cold climate. It is obvious that for terminal design temperatures higher than this, evacuated tube collectors would be clearly superior.

The collector performance curve presents a great deal of information in a simple form. The principles that govern collector performance need to be understood by system designers in order to allow the system to make the best use of the chosen collectors. The performance curves also present the starting place for doing long-term performance analyses of entire systems in real applications.

The collector heat loss coefficient U_L, is far from constant and in many cases is a gross assumption. Convection and radiation losses from even a glazed, insulated collector are not linear. Collectors are generally tested at 0 mile per hour wind speed, and even low winds have a pronounced effect on heat loss. Radiation losses are strictly non-linear, increasing the U_L by 20 percent between 0^oF and 100^oF. This nonlinear radiation loss is especially true for plastic glazed collectors or collectors without a selective absorber coating. However, the assumption that U_L is constant is necessary to allow the performance graph to yield information without added complexity. This assumption should be taken into account when doing long-term perfromance evaluations of actual systems in real applications. It can grossly over-estimate the performance of high heat loss collectors (imagine the effects of wind speed on an unglazed swimming pool panel) and will do no justice at all to collectors with very low heat loss such as evacuated tube designs.

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MONTANA
SOLAR
HOT WATER

EXPANSION TANK SIZING FOR SDHW SYSTEMS

DNRC
Energy Division
Capitol Station
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Natural Resources and Conservation

SDHW SYSTEM EXPANSION TANK SIZING EXAMPLE

The solar collector loop in a closed-loop, antifreeze SDHW system requires an expansion tank to accept the volume expansion or contraction of heat transfer fluids, such as glycol/water mixtures, hydrocarbon oils, and silicone oil, as the temperature of the fluid changes. Each type of heat transfer fluid has a different rate of expansion or contraction per degree of temperature rise or fall as shown in the table of "Comparison of Heat Transfer Fluids."

For example, water expands 0.025% per ^{o}F of temperature rise. If we filled a closed solar loop, i.e., collectors and tubing, with 5 gallons of water at $50^{o}F$ and heated the water to $200^{o}F$, the water would expand:

$$(5 \text{ gal}) \quad \frac{0.025 \text{ gal}}{100 \text{ gal} - {}^{o}F} \quad (150^{o}F \text{ rise}) = 0.188 \text{ gallons.}$$

If we have a pressure relief valve in the loop, which is critical to avoid dangerous pressure build-up, this expansion from 5 to 5.188 gallons will cause the relief valve to discharge water. The addition of an expansion tank to the loop allows the fluid to expand without lifting the relief valve.

The "Comparison of Heat Transfer Fluids" shows that glycol/water mixtures and hydrocarbon and silicone oils expand 1.4 to 2.2 times as

much as water for a given temperature rise. This indicates that expansion tanks for these fluids must be sized larger than those for water.

The common type of expansion tank used in closed-loop, antifreeze SDHW systems is the pressurized captive air, diaphragm-type expansion tank. The tank has a flexible elastomer diaphragm that separates the pressurized air from the fluid and allows the fluid to expand and contract. (Note: The type of elastomer for the diaphragm must be compatible with the heat transfer fluid.)

In order to size a diaphragm expansion tank, the first step is to determine the volume of fluid the closed solar loop will contain. This includes the collectors, tubing and fittings, and heat exchanger. The following guidelines can be used to estimate the volume of fluid contained by the components in the loop:

Flat-Plate Collectors	0.7 - 1.9 gal/collector (depending on size)
1/2" Type L Copper Tube	0.012 gal/ft
3/4" Type L Copper Tube	0.025 gal/ft
1" Type L Copper Tube	0.043 gal/ft
Heat Exchanger	0.10 - 0.40 gallons (depending on type of exchanger)

The following table gives data for typical diaphragm expansion tanks used in SDHW systems:

Standard Dimensions (diameter x height) (in inches)	Total Tank Volume (gal)	Acceptance Volume for Fluid Expansion (gal)
8 x 11 1/2	2.4	0.8
11 x 14	5.7	1.9
11 x 23	9.4	3.1

We can now use the information given to size an expansion tank for a SDHW system.

EXAMPLE

Size an expansion tank for the closed-loop antifreeze (prophylene glycol/water) SDHW system described in Example 2 of the "Pump & Tube Sizing Examples." Assume that the temperature of the glycol/water mixture at the time of filling the system is 70°F and that the maximum temperature reached by the mixture is 320°F (the collector stagnation temperature).

First we must estimate the volume of fluid contained in the solar collector loop:

2 - 4' x 8' collectors	(2 x 1.3) gal	=	2.6
50 ft - 3/4" Type L Tubing	(50 x 0.025) gal	=	1.25
Heat Exchanger	0.3 gal	=	0.3
	Total		4.15 gal

The volume expansion of a 60/40 mixture of propylene glycol/water is 0.041% per ^{o}F (as given in "Comparison of Heat Transfer Fluids").

So the maximum fluid expansion that can occur is:

$$(4.15 \text{ gal}) \frac{0.041 \text{ gal}}{100 \text{ gal} - {}^{o}F} (320^{o} - 70^{o}F) = 0.425 \text{ gallons.}$$

We require an expansion tank with an acceptance volume of at least 0.425 gallons. We see from the data table for typical expansion tanks that the 8" x 11 1/2" tank has an acceptance volume of 0.8 gallons so we would select this tank.

Guidelines for expansion tank and solar loop pressures in typical residential SDHW systems containing 3 to 8 gallons of fluid and a fluid temperature of $70^{o}F$ at the time the system is filled are:

Expansion Tank Pressure	27 - 30 psi
Solar Loop Pressure	30 - 50 psi (for 8 and 3 gallon fluid volume, respectively).

Further details about expansion tank sizing, pressure guidelines, selection of compatible diaphragm materials, etc., can be obtained from expansion tank manufacturers.

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MONTANA
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CONTROLLERS AND SENSORS FOR SDHW SYSTEMS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

MOTHER EARTH AND CONTROLLERS

NOTE: Though little can be done to protect controls from a direct lightning strike, grounding the collector array will prevent damage from "near strikes." Please take a few minutes to read this article* and pass it on to your installers.

Most metallic absorber plates incorporated with glass or plastic and insulation usually contain all of the elements of a capacitor--a device for receiving and temporarily storing an electric charge. Dielectric unions (nonmetallic connections between piping and/or joints), popular as a means of combatting absorber plate corrosion, serve to electrically isolate the collector and allow these static charges to build and to eventually discharge down the sensor line and through the controller. While our controllers are designed to withstand normal static charges, a collector plate can be charged to a level that can devastate solid-state circuitry.

Electric charge on an ungrounded metal collector can occur in two ways. Electrostatic charges can be generated by windswept particles bouncing off a plastic or glass glazing material. The phenomenon is

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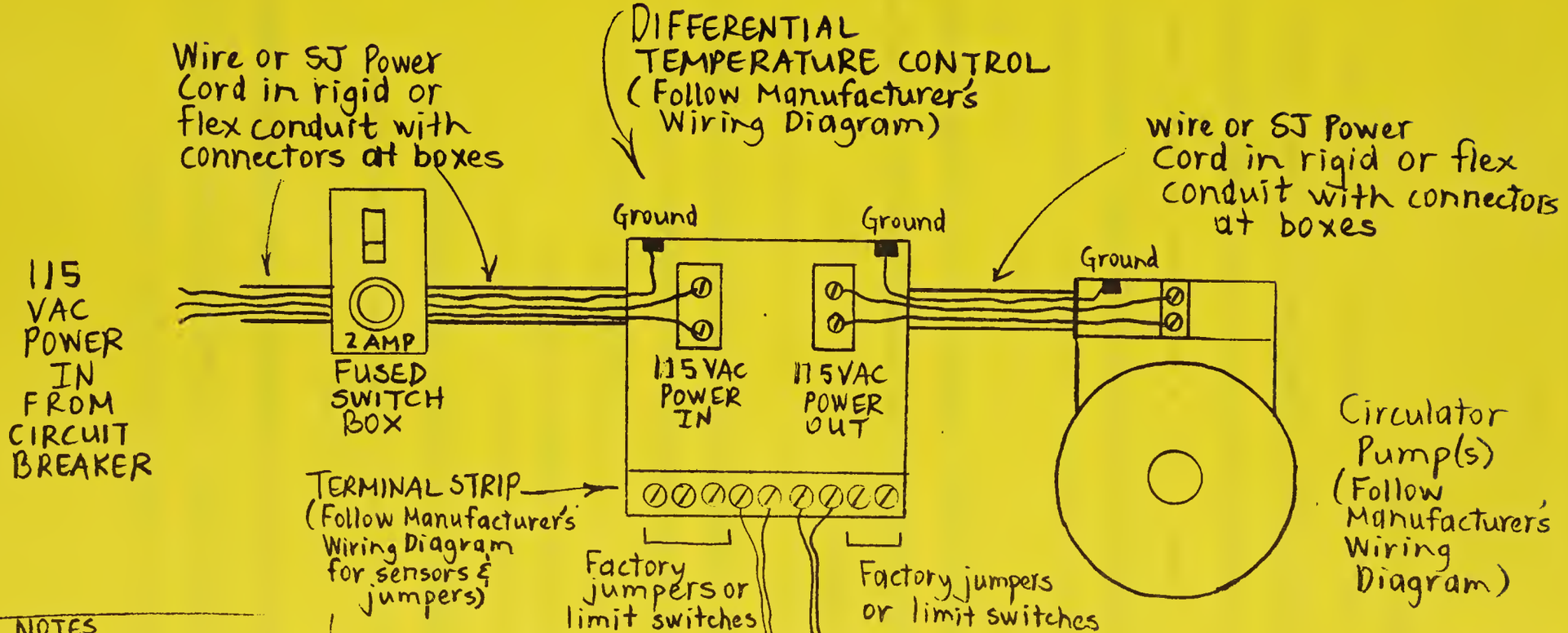
GENERAL WIRING DIAGRAM FOR SDHW SYSTEM CONTROL


Wire or SJ Power Cord in rigid or flex conduit with connectors at boxes
DIFFERENTIAL TEMPERATURE CONTROL (Follow Manufacturer's Wiring Diagram)
wire or SJ Power Cord in rigid or flex conduit with connectors at boxes
115 VAC POWER IN FROM CIRCUIT BREAKER
2 AMP FUSED SWITCH BOX
Ground
Ground
Ground
115 VAC POWER IN
115 VAC POWER OUT
TERMINAL STRIP (Follow Manufacturer's Wiring Diagram for sensors & jumpers)
Factory jumpers or limit switches
Factory jumpers or limit switches
Circulator Pump(s) (Follow Manufacturer's Wiring Diagram)

NOTES

1) Follow Electrical Code.
2) Ground collectors to plumbing & jump dielectric unions if necessary.
3) Wiring to be neat & securely attached.
4) Know control check-out procedures and apply them.

THERMISTOR SENSOR FOR COLLECTOR (PREFERABLY ATTACHED TO BACK OF ABSORBER PLATE)

THEMISTOR SENSOR FOR STORAGE TANK (PREFERABLY MOUNTED IN THERMOWELL IN BOTTOM OF TANK)

Low Voltage Sensor Wire (Twisted 2-Conductor 18 AWG in protective waterproof plastic jacket) (make joints with wire nuts or solderless crimp connectors & seal with silicone)

DO'S AND DON'T -- SENSOR WIRING

A control is as good as the information it receives from its sensors. Improperly installed sensors can cause "nightmares" for the homeowner and service person. Take a few minutes to familiarize yourself with these guidelines and pass them along to your field personnel.

-- Don't run sensor wiring in parallel with AC lines unless shielded wire is used. This prevents interference by other electrical signals.

-- Protect sensor connections from moisture by pressing silicone seal or RTV into the wire nut after hookup. For proper electrical contact, use quality wire nuts or solder connections. Do not tape wire together.

-- Protect the sensor itself from exposure to ambient temperatures. Insulate properly for accurate readings.

-- Ensure proper conductivity to sensors not in direct contact with the heating medium. Use thermal grease or a conductive epoxy between the sensor and mounting surface.

similar to getting a shock after walking across a carpet on a dry day. When the plastic or glass becomes so charged, the ungrounded metal plate acquires an equal but opposite charge.

The other method of inducing an electric charge on an ungrounded metal collector plate is for a charged cloud or near lightning strike to produce the charge.

Providing a good metallic path to Mother Earth will prevent this kind of damage except in the event of a direct or near direct lightning strike. All metal solar collectors and support structure parts must be grounded to a cold water supply or to a grounding rod driven to a cold water supply or to a grounding rod driven into the earth. One word of caution when grounding to the cold water supply. Often plumbing systems use plastic piping or Teflon taped joints. Both will interrupt the discharge path, causing it to look for another avenue. Therefore, minimize the likelihood -- go directly to Mother Earth and keep a satisfied customer.

One of the major skills of a service technician is trouble-shooting. The process involves the following steps:

1. Carefully observing the symptoms,
2. Analyzing the possible causes,
3. Limiting the possibilities.

The first thing to remember is that trouble-shooting is a logical and orderly process. Think of "GOAL."

Good troubleshooting involves:

Observing the symptoms --

Analyzing possible causes --

Limiting possibilities --

A controller that appears to be malfunctioning usually shows very definite symptoms. These symptoms are extremely important. Good service personnel try to note all the symptoms before proceeding. This demands a knowledge of the controller. Obviously, you must know what the normal performance of the controller is to be able to identify what is abnormal. For example, if a pump runs well into the night, it could indicate incorrect sensor placement, although it could possibly be normal operation. Knowing the contoller will help the service technicians to properly observe the symptoms.

Once the symptoms are clearly identified, it is time to analyze possible causes. This part of the trouble-shooting involves a general knowledge of the logic behind the controller. Experienced service technicians "think" the logical sequence. Their experience tells them what is required by the controller to make decisions. An ohmmeter will tell the technician if the sensors are "opened" or if they have "shorted." A voltmeter will verify control inputs and outputs.

-- Use 18 AWG "bellwire" for sensor wiring runs shorter than 100 feet in length. Use shielded cable for runs longer than 100 feet.

-- Install a panel sensor at the hottest point in the array (usually at the outlet of the last collector). If a metal absorber is used, attach a (bolt) sensor to the back of the plate.

-- Install the storage sensor securely against the side of the tank.

-- Don't expose the sensor to open flame or soldering. Thermal shock may damage the sensor and cause false readings.

-- Before attaching the sensor control, take an ohm reading and compare it to a resistance/temperature chart that matches sensor specification (e.g., a 10K ohm sensor at 77°F will have a different reading than a 3K ohm sensor at the same temperature). This will reveal open or short circuits that might result in call-backs or lost time searching for a fault after the system is installed.

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Galvanic And Stray Current Corrosion: Causes And Prevention

Prepared for Ohio State University
by
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GALVANIC AND STRAY CURRENT CORROSION: CAUSES AND PREVENTION

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Synopsis

The problems of galvanic and stray current corrosion are reviewed with respect to effects of environments, alloys, and arrangements of equipment. Where available, quantitative data are cited.

Galvanic corrosion involves accelerated effects due to coupling two metals of different galvanic potential together. The more anodic materials corrode faster than if uncoupled.

Stray current corrosion occurs in the presence of DC currents where it inadvertently enters an alternate (but unintended) path. The sites of entry and leaving produce extraordinary anodes and cathodes which would not exist without the stray current.

The most effective method for preventing the acceleration of corrosion due to galvanic and stray current causes is to use dielectric unions.

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1.0 Introduction

The purpose of this memorandum is to describe important engineering aspects of *galvanic corrosion* and *stray current corrosion*. Specifically I wish to describe what these phenomena are, what causes them, and how they are controlled. These phenomena both have been discussed extensively in the technical literature and appropriate references are given here. These phenomena are among the most aggressive of corrosion phenomena and should be scrupulously avoided even in low cost engineering applications since either phenomenon can destroy an installation in a matter of a few weeks under generally innocuous (apparently) conditions.

2.0 First: What is "Ordinary" Corrosion?

The natural state of most metals is in the "combined" state as oxides, sulfides, carbonates, etc. Metals "want" to react to form compounds. Metals may also dissolve as soluble ions like Fe^{++} because those ions are more stable than the metal in most cases. Corrosion, then, is simply the process of a metal forming such compounds or ions.

A very slow rate of these reactions is desirable and is frequently obtained for many metals in various engineering environments. Thus, metals can be predicted to have lifetimes of 5, 10, 15 years and sometimes many hundreds of years depending on how fast this degradation process actually occurs.

With the exception of gold and platinum *all metals corrode* to some degree in engineering environments. Even these noble metals corrode in the alchemists's aqua regia.

Most engineering metals—except copper— will corrode in plain water with no oxygen present. However, with oxygen the rate of corrosion is usually faster but not always.

To a large extent many metals corrode by a relatively uniform reaction or dissolution of metal. Such corrosion is common for metals exposed in tap waters, ground water, sea water, high temperature oxidation, and chemical processing. The corrosion rates in "uniform" corrosion may be as low as 0.01 mils per year or as high as several inches per year.

Unfortunately, there are several ways that *corrosion* can be greatly *accelerated*. These accelerated processes may transform a slowly corroding situation into one that may penetrate the metal at rates as high as *tenths of inches per hour*. Naturally, there is a wide range of severities between the most serious of the accelerated forms of attack and plain uniform attack. References 1-6 describe these various forms of attack in detail.

Some of these forms of accelerated corrosion attack include the following:

1. Pitting: Here the attack localizes and actually drills holes in metals. The overall attack on the rest of the metal is slow but these localized chemical "drills" progress rapidly and may perforate a tube wall in several weeks. Pitting is frequently caused by the presence of chloride ions and is accelerated by the presence of oxygen in the solution.
2. Intergranular attack: Metals are made of grains or small crystallites. The boundaries between these grains often have a different composition which, depending on the environment, may corrode perferentially. Aluminum alloys and stainless steels in certain fabricated conditions are severly attacked in this way.
3. Crevice attack: If deposits are present on metal surfaces, corrosion may be accelerated in the crevice underneath the deposit. Further, if two metals are joined together, as at a flange, in very intimate contact, corrosion may be accelerated in this crevice.
4. Stress Corrosion Cracking: If a metal is exposed to an *environment* and the metal is stressed above some nominal value, there is sometimes a conjoint stress-environment action which causes the metal to crack in a brittle fashion. Such failures are often observed in all metals but under special circumstances.

3.0 Galvanic Corrosion

While all metals corrode, certain metals *corrode much faster* when *coupled* or connected with other metals.

3.1 The Battery Anology

The familiar experiment in high school chemistry, indeed my daughter has also done it, is to connect two metals like zinc and copper. After immersing this couple in an electrolyte—like lemon juice— a current flows.

The current that flows between two metals of different composition is the basis for the battery.

A most familair battery has zinc on the outside with a graphite core. When these two materials are connected, a current flows. If the battery is left unconnected, the zinc eventually corrodes and a new battery must be found.

The current in the zinc-graphite battery arises because the zinc *corrosion* is *accelerated* when connected to the graphite.

Figure 1 shows a typical schematic of a zinc – graphite battery.

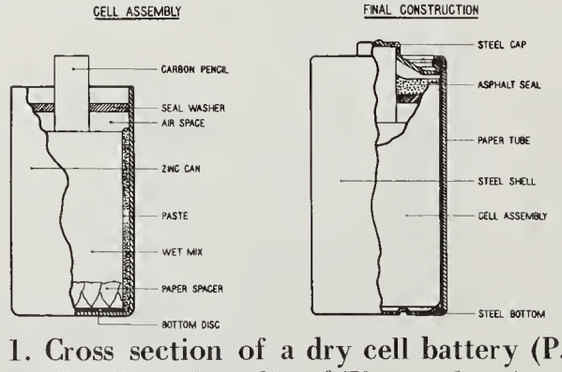


Figure 1. Cross section of a dry cell battery (P. 73, *The Encyclopedia of Electrochemistry* Ed. Hampel, Reinhold).

The zinc corrodes according to

$$Zn \rightarrow Zn^{++} + 2e \quad (1)$$

So, for every ion of zinc produced we get two electrons. This gives the battery current—but at the same time the battery corrodes relatively rapidly.

At the graphite no corrosion occurs but there is a reaction because the electrons of reaction (1) must go somewhere. These electrons may be consumed by a reaction as simple as the reduction of water which consumes electrons:

$$H_2O + e \rightarrow OH^- + 1/2H_2 \quad (2)$$

or by a more complicated reaction. The usual reaction for the system in figure 1 is the reduction of MnO_2 according to

$$MnO_2 + H^+ + 1e \rightarrow MnO(OH) \quad (3)$$

This reaction occurs at the carbon pencil.

In the case of our simple zinc-copper battery, the reaction in (2) or the reduction of oxygen from solution

$$O_2 + 4H^+ + 4e \rightarrow 2H_2O \quad (4)$$

consume electrons.

Now note neither reaction (2), (3), or (4) cause corrosion of the material. Thus, by connecting zinc to copper as to graphite we end up with more area for reactions (2), (3), or (4) but the zinc continues to corrode according to reaction (1). *With this increased capacity to absorb electrons the corrosion of the zinc is accelerated or reaction (1) occurs more rapidly.*

The site at which *corrosion* occurs or electrons are produced is called the *anode* and the site where electrons are used up is called the *cathode* (as in 2, 3, and 4 above).

The battery works then (or *zinc corrodes* rapidly) *only when* the zinc is *connected* by a metallic contact. This acceleration occurs as a result of increased area for the reduction reactions such as (2), (3), or (4) which do *not* involve at the same time more anodic or corrosion activity.

3.2 Galvanic Corrosion—The Unwanted Battery

Suppose we wish to connect a steel pipe to a copper one, we have the exact situation as described from the battery. Iron with respect to copper is just like zinc with respect to copper. And like the zinc, *iron corrodes more rapidly than it would if it were not connected* to the copper. Thus, an iron-copper cell would be a battery just like zinc-copper one. Except—we don't want this battery because now it is operating to destroy, prematurely, a piece of industrial hardware.

Galvanic corrosion, then, *is that which results from the accelerating effect of connecting two metals together.* Examples of such combinations which would be bad are the following:

Anode (It corrodes more rapidly when connected)	*Cathode (It doesn't corrode)*
Aluminum	Iron
Aluminum	Copper & its alloys
Aluminum	Stainless steel
Iron	Copper & its alloys
Iron	Stainless steel
Zinc	Iron
Zinc	Copper

In a general way, it may be said that when two dissimilar metals are connected together one of them will corrode preferentially and at a more rapid rate than if uncoupled. The amount of acceleration varies greatly from nothing to factors of ten depending upon circumstances discussed in subsequent sections.

3.3 Coupling the "Same" Metal

Galvanic acceleration may occur even if the same alloy is jointed to itself.

Suppose that a pipe which has been operating for a long time springs a leak. This bad pipe is then cut out and removed; a new one of the same composition is welded in as a replacement. But a short time later it fails—Why should this occur in view of the materials having the same composition? The answer to this apparent anamoly is that the old pipe has developed a good protective film whereas the fresh pipe has not.

The reduced reactivity of the old pipe makes it noble and accelerates the corrosion of the new pipe which never gets a chance to protect itself.

3.4 The Relative Area Effect

Until now we have considered only the difference in composition of the two metals. In addition, we are concerned about the *relative areas* of these two metals.

We said in section 3.1 that the corrosion of the anodic material is accelerated because the cathodic material provides additional area on which the electron absorbing reactions—i.e. like (2), (3), and (4) may proceed.

If we then connected an anodic material like iron to a cathodic material like copper—but suppose the copper was 1/100 of the area of the iron—there would be very little acceleration of corrosion of the iron. If we now increase the relative area of the copper to 1:1 and 100:1, clearly the iron will corrode progressively more rapidly although not necessarily in direct proportion.

Thus, an iron bolt in a copper plate would corrode very rapidly; whereas the reverse—a copper bolt in an iron plate—would not cause significant acceleration.

Figure 2 shows an example of area effects which may be prone or not prone to aggravated attack. 2A shows an aluminum rivet in a copper sheet. Here, the anode, aluminum, will corrode very rapidly because the Cu/Al ratio is large. In the second

case (B) the Al area is large with respect to the copper and will corrode slowly. A small amount of aggravated attack would be expected at the interface for (B) whereas in the case of (A) the Al will corrode out rapidly.

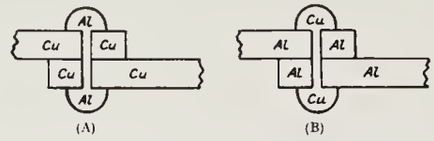


Figure 2. (A) Cu joined with aluminum rivets giving a *high* Cu/Al area (cathode/anode), (B) Al joined with copper rivets giving *small* Cu/Al area. From Evans, p. 194, ref. 1.

3.5 The Nearness Effect

If the two dissimilar metals are adjacent, corrosion is accelerated most at the site where the two metals touch as shown in figure 3.

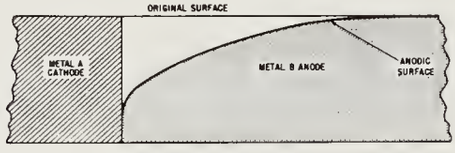


Figure 3. Schematic illustration showing the relative distribution of corrosion when a galvanic couple is in direct contact. (p. 663, Encyclopedia of Electrochemistry)

3.6 What are the Criteria for Accelerated Galvanic Corrosion?

A more active metal will corrode more rapidly when coupled to a less active metal relative to the uncoupled condition. The question is "how much?" and the answer is "It Depends!"

The "It Depends" answer is related to the following:

1. The composition of the two coupled metals.
2. The surface finish of the two coupled metals.
3. The liquid flow rate past the two coupled metals.
4. The dissolved oxidizing species in the solution (oxygen, ferric ions).
5. The species which tend to destroy the protective films (like chloride, sulfide, bromide).
6. The species which tend to form or to improve protective films (carbonate, phosphate).
7. The relative areas of the two galvanic materials.

Having mentioned the above as by way of illustrating that the relative rate of the coupled active material may vary considerably but *there is little question that it will corrode* more rapidly and fail prematurely.

This section gives examples of these galvanic effects for important industrial metals in common industrial environments.

Galvanic or bi-metallic corrosion was studied systematically as early as 1918. Evans quotes the following table for the corrosion of iron in contact with a series of galvanically coupled metals.

TABLE I

BIMETALLIC CORROSION OF IRON AND A SECOND METAL IN 1% NaCl SOLUTION[1],*

Corrosion of Iron (mg.)	*Second Metal*	*Corrosion of Second Metal (mg.)*
183.1	Copper	0.0
181.1	Nickel	0.2
171.1	Tin	2.5
183.2	Lead	3.6
176.0	Tungsten	5.2
153.1	Antimony	13.8
9.8	Aluminum	105.9
0.4	Cadmium	307.9
0.4	Zinc	688.0
0.0	Magnesium	3104.3

* Absence of specimen areas and time prevent giving rates and weight loss per unit area needed for penetration calculation.

While the data shown in Table I lack some necessary details, the fact that the galvanic phenomenon was recognized so early and so clearly is proportional to its industrial seriousness. Note also the reversal of effects when iron is coupled to a more active metal: the corrosion rate of the iron is negligible and we have the phenomenon of *galvanic protection.* We further note that the corrosion of aluminum is accelerated in galvanic contact with iron which is now the nobler of the two materials—the reverse of the iron-copper situation.

The pattern of Table I prompted workers interested in corrosion at the time to arrange metals for galvanic instabilities according to their standard electrode potentials**. Important metals are so arranged in Table II. Here the metals with the most positive values are the most noble and tend to be cathodic; the metals with the more negative would corrode progressively more rapidly and would tend to be anodic when connected to a more positive one.

Despite the apparent reasonability and rationalization of the relative ranking of metals according to their equilibrium tendencies to corrode, *serious discrepancies* arose owing to the existence of protective passive films on the metals. In the cases of *stainless steels, titanium,* and *aluminum* there are many environmental circumstances where these metals operate effectively as *noble* metals owing to the highly protective nature of these films.

** The standard electrode potential is defined for our purposes for the equilibrium $M \rightleftarrows Mn^+ + ne$ where the Nernst equation defines the equilibrium potential E_o for a given ionic concentration $[M^{++}]$ according

$$E_o = E_o^\circ + \frac{2.3\,RT}{nF} \log [Mn^+]$$

Here, E_o° is the standard electrode potential R is the gas constant, T the absolute temperature, n the number of electrodes in the half cell reaction. The values in the Table II are of E_o°. The values of E° and E_o° are in volts.

TABLE II

TABLE OF STANDARD ELECTRODE POTENTIALS
(From Ref. 4)

Metal	*Standard Potential, E_o^o (volts)*
$Li = Li^+ + e^-$	3.05
$K = K^+ + e^-$	2.93
$Ca = Ca^{++} + 2e^-$	2.87
$Na = Na^+ + e^-$	2.71
$Mg = Mg^{++} + 2e^-$	2.37
$Be = Be^{++} + 2e^-$	1.85
$U = U^{3+} + 3e^-$	1.80
$Hf = Hf^{+4} + 4e^-$	1.70
$Al = Al^{+3} + 3e^-$	1.66
$Ti = Ti^{++} + 2e^-$	1.63
$Zr = Zr^{+4} + 4e^-$	1.53
$Mn = Mn^{++} + 2e^-$	1.18
$Nb = Nb^{+3} + 3e^-$	ca 1.1
$Zn = Zn^{++} + 2e^-$	0.763
$Cr = Cr^{+3} + 3e^-$	0.74
$Ga = Ga^{+3} + 3e^-$	0.53
$Fe = Fe^{++} + 2e^-$	0.440
$Cd = Cd^{++} + 2e^-$	0.403
$In = In^{+3} + 3e^-$	0.342
$Tl = Tl^+ + e^-$	0.336
$Co = Co^{++} + 2e^-$	0.277
$Ni = Ni^{++} + 2e^-$	0.250
$Mo = Mo^{+3} + 3e^-$	ca 0.2
$Sn = Sn^{++} + 2e^-$	0.136
$Pb = Pb^{++} + 2e^-$	0.126
$H_2 = 2H^+ + 2e^-$	0.000
$Cu = Cu^{++} + 2e^-$	- 0.337
$2Hg = Hg_2^{++} + 2e^-$	- 0.789
$Ag = Ag^+ + e^-$	- 0.800
$Pd = Pd^{++} + 2e^-$	- 0.987
$Hg = Hg^{++} + 2e^-$	- 0.854
$Pt = Pt^{++} + 2e^-$	ca - 1.2
$Au = Au^{+3} + 3e^-$	- 1.50

In order to meet the needs of this "practical nobility" conferred by protective films, a revised "Galvanic Series" was devised by LaQue[12]. This is given in Table III. This particular scale is arranged in order of increasing nobility. Thus, magnesium is the most anodic or corrodable and passive type 316 is the most noble or corrosion resistant. Connecting a more active material to a more noble material *in the sea water environment* will accelerate greatly the corrosion rate of the less noble material.

TABLE III

GALVANIC SERIES IN SEA WATER

(most active)

Magnesium

Magnesium alloys
Zinc
Galvanized steel or galvanized wrought iron
Aluminum 52SH
Aluminum 4S
Aluminum 3S
Aluminum 2S
Aluminum 53S-T
Alclad
Cadmium
Aluminum A17S-T
Aluminum 17S-T
Aluminum 24S-T
Mild steel
Wrought iron
Cast iron
Ni-Resist
13% chromium stainless steel type 410 (active)
50-50 lead tin solder
18-8 stainless steel type 304 (active)
18-18-3 stainless steel type 316 (active)
Lead
Tin
Muntz metal
Manganese bronze
Naval brass
Nickel (active)
Inconel (active)
Yellow brass
Admiralty brass
Aluminum bronze
Red brass
Copper
Silicon bronze
Ambrac
70-30 copper nickel
Comp. G-bronze
Comp. M-bronze
Nickel (passive)
Inconel (passive)
Monel
18-8 stainless steel type 304 (passive)
18-8-3 stainless steel type 316 (passive)

(most noble)

It is important to recognize that Table III is *developed only for the sea water environment* – similar tables must be developed for the set of materials planned for any complex environment.

3.7 The "How Fast" Question – For Galvanic Elements of Equal Areas

Section 3.6 outlined the criteria for the existence of galvanic couples. Further, it noted the complication in making precise predictions. Recognizing these difficulties we discuss here some of the actual measurements conducted on galvanic corrosion couples.

One study by Fink et al.[18] considered the behavior of an aluminum alloy connected to Monel (Cu-Ni) exposed to sea water which was either aerated or deaerated. A further variable included the presence of copper impurity added as copper sulfate. The data are shown in Table IV.

Table IV shows that the aluminum alloy connected to monel in aerated sea water will corrode 6.5 times faster. The presence of the copper ions in solution increases the overall rates; this copper in a normal engineering system would be expected simply from corrosion of the copper alloy itself. Most important, deaerating the solution decreases the corrosion rates although there is still a factor of two increase in the corrosion rates.

The 8.37 mdd of Table IV corresponds to 5.5 mils penetration per year of the metal. This is a relatively high rate in view of the fact that attack is not completely uniform. The deepest penetration might be expected to be twice the average rate. Thus, a tube wall of 50 mils would be perforated in about 5 years not counting for the loss in strength.

An extensive study was conducted by Compton et al.[16] on a wide variety of galvanic couples. His specimens were 1 sq. in specimens coupled together and separated by filter paper containing the appropriate solution. His measurements, instead of measuring weight change, determined the galvanic current between two electrodes. This system was conducted in such way as to be considered aerated.

TABLE IV

EFFECT OF DEAERATION AND COPPER ION CONTENT ON THE CORROSION BEHAVIOR OF Al-6061-T6[1]

Corrosion Rate, milligrams per dm^2 per day, mdd

Coupling Condition	Sea Water Aerated	Sea Water Deaerated	Sea Water Plus 1 ppm $CuSO_4$[3] Aerated	Sea Water Plus 1 ppm $CuSO_4$[3] Deaerated	Sea Water Plus 10 ppm $CuSO_4$[3] Aerated	Sea Water Plus 10 ppm $CuSO_4$[3] Deaerated
Uncoupled	1.28	0.37	2.48	0.40	3.60	0.44
Coupled to Monel[4]	8.37	0.67	11.66	1.08	12.32	1.20

(1) Al + 0.25 Cu + 0.6 Si + 1.0 Mg + 0.25 Cr

(2) $\frac{\text{mdd x } 1.44}{\text{density}}$ = mil per year So for Aluminum mdd x 0.655 = mil/year

(3) 0.4 and 4.0 copper respectively

(4) Ni + 31.5 Cu + 1.4 Fe

Figure 4 summarizes the results from a variety of metal couples. The results are given in terms of current flowing between the galvanic couples. Essentially, this current represents a net increase over the baseline uncoupled corrosion rates. Shown below Figure 4 is a table giving the equality of current to penetration.

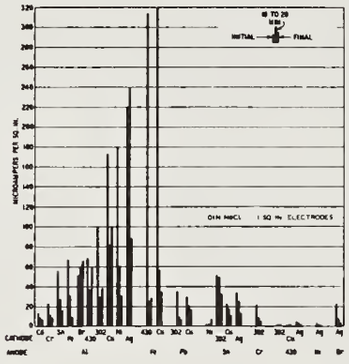


Figure 4. Galvanic currents between two specimens taken for initial, short times (10-20 minutes) and long times (six days) exposed 0.01 N NaCl (about 500 ppm) Ref. 16.

Corrosion Currents for Various Metals

Approximate values of current which would cause the removal of 0.001-inch of metal by corrosion in one year from the specimens in these tests, which have a nominal area of 1 square inch.

Metal	Current (Microamperes)
Aluminum	13
Cadmium	7½
Chromium	20
Copper	7
Iron	14
Lead	5
Magnesium	14½
Nickel	14½
Tin	6
Zinc	10½

Note that the initial currents are very high whereas the, final are lower. The final readings are those which may be taken as the long term values. Thus, at long times the Fe-Cu couple will corrode at 2 mils per year above the base corrosion rate. *However,* this is true for the specific case of specimens separated by filter paper where the corrosion products can build up to stifle reaction. *On the other hand* in a flowing system, the initial values might be closer to the appropriate ones; and in this case the *Fe of the Fe-Cu couple would corrode at 23 mils per year.*

In a study by Ketcham and Beck[15] Mg-Al couples were studied in 0.1N NaCl. For electrodes of equal size they found the steady state current between two electrodes to be 1800 microamps per in^2 corresponding to about *1300 mils per year* or 1.3 inches per year.

Another study by Paige and Ketcham[14] involved the coupling of specimens of various alloys to titanium or stainless steel exposed to sea water. Both elements of the couples were the same size. Their data for a 1.0 N NaCl test at room temperature are given in Table V taken from reference (14).

TABLE V

Penetration rates in *mils per year* from galvanic couples exposed in 1.0N NaCl*. Temperature 30°C, test 48 hours

Corrosion Rates of Anodic Material, mpy

Anodic Material	Uncoupled	Coupled to Stainless Steel Type 321	Coupled to Commercially Pure Ti
75S-T6	2.14	26.8	42.7
Brass(60-40)	3.95	3.8	4.7
Cd	1.5	14.8	15.5
Cu	5.0	7.5	12.4
Fe(4130)	13.2	62.5	55.0
Inconel	0.0	0.0	0.0
Mg(J-lh)	85.5	2888.0	1230.0
Ni	0.485	0.33	0.39
Pb	6.25	12.6	12.3
Sn	1.19	7.3	6.7
Zn	25.2	71.0	57.0

Taken from Tables 2 and 3 of reference 6. The mdd data in the original are converted to mils per year.

The data of Table V show the wide range of galvanic rates as affected by titanium and stainless steel base materials. In some cases, like brass, copper nickel, and inconel there is little effect of coupling; in other cases, like Mg, the effect is enormous. An important case involves coupling iron to stainless steel where the coupling increases the rate by five times.

3.8 The Area Effect – How Much Faster

The "how fast?" question discussed in section 3.7 considered specimens of *equal areas* and arranged to be parallel and opposite i.e. *facing plates.*

In section 3.4 we mentioned that increasing the area of the cathode relative to that of the anode would increase the corrosion rate of the anode.

The accelerating effect of increasing the cathode/anode ratio is shown in figure 5 from the paper by LaQue[12].

The clear effect here is an increase in the rate of six times.

This area effect shows qualitatively what should happen at the interface between two parallel specimens in the same plane i.e. one tube connected to another of a different composition. Thus, at the interface the galvanic effect would be accentuated as depicted as in figure 3.

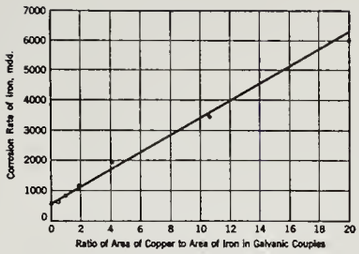


Figure 5. The effect of cathode (Cu) to anode (Fe) area ratio in 3% NaCl. Area of iron anode 0.047 dm.^{2} and area of Cu cathodes: 0.024 to 0.94 dm.^{2} 1000 mdd = 184 mils per year

3.9 So How Do We Stop Galvanically Accelerated Corrosion?

Galvanically accelerated corrosion may be absolutely stopped by *interrupting the electrolyte or electronic paths* between two materials. This is illustrated in figure 6.

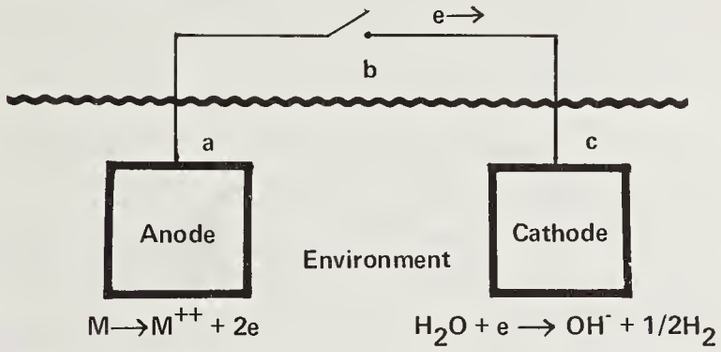


Figure 6. Schematic arrangement of electrodes showing location of anodic and cathodic processes. The electrolyte solution may be damp earth, potable water, sea water, or a damp film of moisture on metals exposed in atmospheric conditions. The switch indicates the possibility of breaking the galvanic couple or the stray current system by using a dielectric.

Since it is frequently difficult to interrupt the environmental path, *it usually is easiest to place an electrically insulating material in the electronic path.*

We may thus avoid all aspects of galvanically accelerated corrosion by placing a dielectric between the two materials. This is the same as opening the switch of figure 6. Once the current carrying path is broken, the galvanic effect stops. The material will then corrode at its normal non-accelerated rate.

There are other ways of mitigating the effect of galvanically accelerated corrosion. These have drawbacks or limited applicability but may work very well in some cases. These approaches include:

1. Lowering the oxygen content as shown in Table IV lowers the coupled as well as uncoupled corrosion rates.
2. Painting the cathode surface reduces the cathode/anode area ratio; note that if the anode only is painted, any fissure in the coating will be the site of a greatly aggravated localized attack.
3. There are certain substances which can be added to the solutions to inhibit the anodic or cathodic reactions. Slowing down either reaction will slow the total corrosion process.

The above will be recognized as providing relief in special cases but in general industrial environments the above three procedures are *not nearly so clear cut and definite as using a dielectric coupling.*

4.0 Stray Current Corrosion

4.1 Introduction

Understanding the stray current problem is most easily approached by understanding a simple direct current electrolytic circuit. Suppose in figure 6 that the current is moving in the direction shown for the electrons, i.e. from a⟶b⟶c. At the anode the metal ions, M^{++}, and electrons are produced. These electrons move to the cathode and are consumed in the reduction of water to hydrogen.

As long as the current moves in a single direction as shown in figure 6 the corrosion will occur at the site where the electrons leave the surface; the cathodic process will occur where the electrons arrive at the surface.

If the direction of the current is alternating, as in alternating current, no net current flow occurs since the average direction of the current is zero.

Thus, those conditions which favor a direct current will produce corrosion at the anode and one of the reduction processes at the cathode.

4.2 Occurrences of the Stray Current Problem

As a first diagnostic tool, it is worth looking at these industrial circumstances where direct currents are involved.

One of the early manifestations of stray current involved street cars as shown in figure 7 and schematically in figure 8.

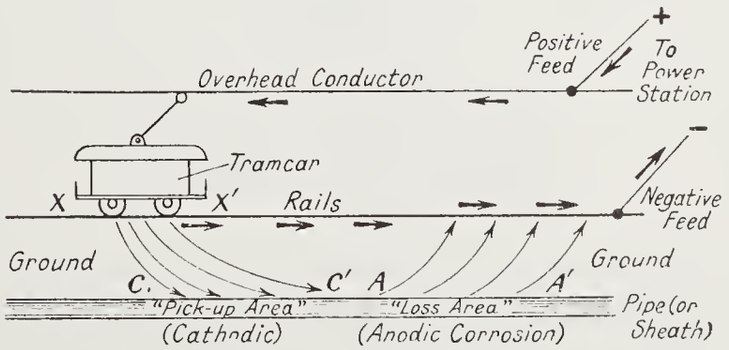


Figure 7. Corrosion of buried pipes by stray currents (the arrows show the direction of "positive" electricity). Reference 1.

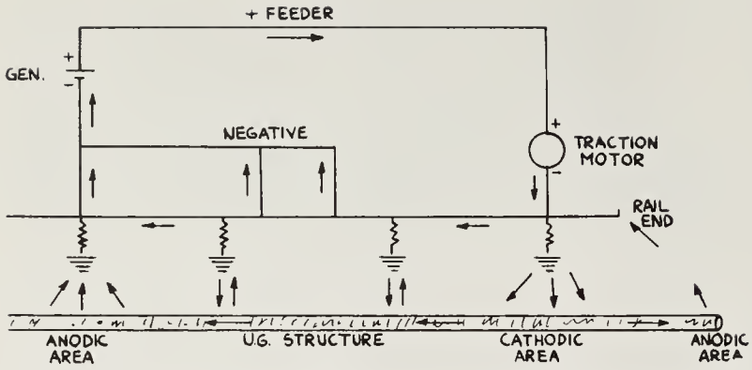
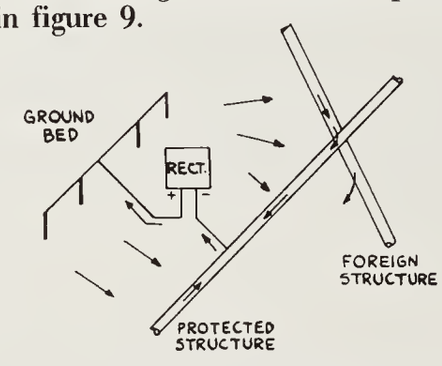


Figure 8. In the railway traction system current is supplied from the generator over aerial wire to the traction motor and returns to the generator over several paths. Generally the rails are not insulated from the earth so that part of the return current travels through the earth and makes use of any metallic underground path in the vicinity which provides conductivity. Reference 24.

The essential idea illustrated in figures 7 and 8 shows an alternate return path for current beside the normal one—the rails. Suppose that there is a discontinuity in the rails owing to a construction error; also, suppose a relatively highly conducting soil—perhaps due to excess salting of the streets. The *discontinuity in the normal current return*, plus an *alternate easy path* through another structure are the essential requisites for the stray current problem.

Having met these conditions favorable to the stray current problem, we have the same circumstance as illustrated in figure 6. We have an anodic and cathodic region. At the anodic area we may expect accelerated corrosion.

Another stray current problem is associated with the use of underground cathodic protection as illustrated in figure 9.



-Stray current originates from a cathodic protection system because some return current from the anode bed uses a portion of the foreign pipe as a part of the return path instead of returning directly through the earth to the protected structure.

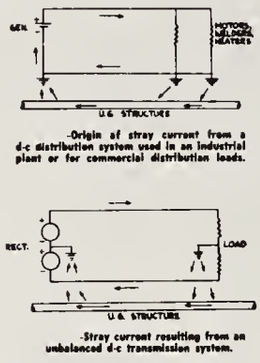
Figure 9

Here the ground bed consists of anodes and the protected structure is thereby maintained as the cathode. However, a foreign structure may also be nearby—as in the case of a buried telephone cable. If the cathodic current goes also the foreign object and *then* goes to the protected structure—the point of exit of current on the foreign structure will realize the accelerated corrosion.

Other operations which may cause stray current problems are:

1. Note again the wide range of cathodic protection applications
2. Welding operations
3. Electric railways
4. Plating baths (i.e. chromium plating, or electro galvanizing)
5. Electrical signals
6. Metallurgical processing where electro-refining in involved (aluminum production)
7. Painting operations involving electro-transport

These various sources of direct current are illustrated in figure 10.



-Origin of stray current from a d-c distribution system used in an industrial plant or for commercial distribution loads.

-Stray current resulting from an unbalanced d-c transmission system.

Figure 10

4.3 Prevention of Stray Current Corrosion

A variety of methods are available for preventing accelerated corrosion due to stray currents. These include primarily

1. Improvement of standard metallic path for removal of currents
2. Interrupting the electrical continuity of the underground structures as by dielectric joints.

5.0 Application of Dielectrics

Section 3.9 and 4.3 describe methods for mitigating galvanic and stray current corrosion respectively.

Of the various approaches for stopping stray current corrosion, the *use of dielectric joints* is the most positive.

In most industrial circumstances it is impossible to assure that other preventative measures — oxygen control, addition of inhibitors, surface treatment, control of water chemistry — are performed with the vigilance and thoroughness necessary to prevent the catastrophic effects of galvanic or stray current processes.

In other words, the dielectrics come closest to being "goof proof" of all the various protective measures.

Dielectrics offer another most important advantage. Should the corrosion occur from an environment not expected, they still work. Thus, if the user is worried normally about the solution within the pipes, he might forget the possibility of external environments. A pipe carrying deaerated water internally may be corroded from the outside by ground waters containing higher chloride and extensively oxygenated. Without a dielectric this external environment might produce catastrophic degradation.

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MONTANA
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PUMP AND TUBE SIZING FOR SDHW INSTALLATIONS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

SDHW System Pump & Tube Sizing Examples

EXAMPLE 1

A closed-loop, siphon-type water drain-back SDHW system will be installed in a residence. The system will include two roof-mounted 4' by 8' flat-plate solar collectors connected in parallel, a 6-gallon drain-back tank, and a 120-gallon solar storage tank with a finned copper tube coil heat exchanger located in the bottom of the tank.

We wish to size a centrifugal pump and the solar collector loop supply and return tubing for this SDHW system.

Assumptions

1. The distance between the water level in the drain-back tank and the return line as it exits the solar collectors (the highest point in the solar collector loop) is estimated to be 15 ft after the installation is completed. This is the "static head."

2. The collector manufacturer recommends that the water flow rate for each collector is 1.5 gallons per minute.

3. The total length of copper tubing in the solar collector loop (supply and return lines) is estimated to be 500 feet and will include 15 90° copper elbows. We will consider two sizes of Type L copper tubing for the loop - 1/2" and 3/4".

Calculations

Since each collector requires 1.5 gpm and the two collectors are connected in parallel, the total flow rate through the collector loop (collectors, supply and return tubing, drain-back tank, pump, and heat exchanger) is 3 gpm.

The pressure drop or head loss, expressed in feet of water, for each component in the loop must be found. These component pressure drops will then be added to find the total pressure drop or head loss. A pump capable of delivering 3 gpm at the total pressure drop will then be selected.

It is important to note that this system is a closed-loop, siphon-type drain-back system. When the system starts, the pump must be capable of generating 15 feet of water head (the static head) to push water over the high point in the system. Once the water begins to "fall over" the high point, a siphon will be established and the pump no longer needs to generate the static head. However, the pump must then generate the "flowing" or "operating" head necessary to overcome friction pressure drop through the collectors, tubing, and

heat exchanger. This means that the pump has two "operating points" - one at start-up when the siphon is not established and one at operation when the siphon is established.

If the system is an open-loop or oversized-return drain-back system in which a siphon is never established, the pump must always generate sufficient head to overcome the static plus the operating heads.

Now we find the component pressure drops.

Solar Collectors

The collector manufacturer's data sheet gives a pressure drop of 0.05 ft water per collector at 1.5 gpm water flow. Since the collectors are in parallel, this pressure drop of 0.05 ft water is the total across the two collectors. (Note: If the collectors were in series, we would add the drop for each collector and get a total of 0.10 ft water.)

Heat Exchanger

The exchanger manufacturer's data sheet gives a pressure drop of 5 psi at a water flow rate of 3 gpm. To convert psi to ft water, we multiply by 2.31 and get a total heat exchanger pressure drop of 11.55 ft water.

Copper Tubing and Fittings

We will look at both 1/2" and 3/4" Type L copper tube sizes. Figure 2 (page 12) of the Copper Tube Handbook gives the following pressure drops with a water flow rate of 3 gpm:

1/2" Type L - 8 psi (or 18.48 ft water) per 100 ft of tube

3/4" Type L - 1.8 psi (or 3.23 ft waater) per 100 ft of tube

We can also use this Figure 2 to determine that the velocity through the tubing for 3 gpm of water flow is approximately:

1/2" Type L - 4 ft/sec

3/4" Type L - 2 ft/sec.

The "rule of thumb" for maximum velocity to prevent erosion and noise is 4 to 6 ft/sec, so either 1/2" or 3/4" Type L tubing is satisfactory.

Table 8 (page 13) of the Copper Tube Handbook shows that a 1/2" 90° elbow is equivalent to 1 foot of 1/2" copper tube in terms of pressure drop and that a 3/4" 90° elbow is equivalent to 1.25 feet of 3/4" tube. Therefore, in our system with 15 elbows, these fittings are equivalent to the following:

15 - 1/2" 90° elbows = 15 feet of 1/2" tube

and

15 - 3/4" 90° elbows = 18.75 feet of 3/4" tube.

Now we can get the total pressure drop for the tubing and fittings:

for 1/2" tubing, (50 + 15) ft tubing x $\frac{18.48 \text{ ft water}}{100 \text{ ft tubing}}$ = 12.01 ft water

for 3/4" tubing, (50 + 18.75) ft tubing x $\frac{3.23 \text{ ft water}}{100 \text{ ft tubing}}$ = 2.22 ft water

Total Operating Pressure Drop or Head Loss

Now we can add the component pressure drops for the 1/2 " tubing and 3/4" tubing cases:

	1/2" tubing	3/4" tubing
Collector	0.05 ft water	0.05 ft water
Heat Exchanger	11.55 ft water	11.55
Tubing & Fittings	12.01 ft water	2.22 ft water
Total Operating Pressure Drop	23.61 ft water	13.82 ft water

Pump Selection

In the case of 1/2" tubing and fittings for the solar collector loop, we require a pump that can generate a maximum of about 24 ft water head at 3 gpm water flow (the "operating" pressure drop).

Referring to the pump curves, we see that the following pumps are capable of 24 ft water head at 3 gpm:

1. Single 009, 1/20 HP
2. Signle UP 40-75V, 1/6 HP
3. Single UP 26-96F, 1/12 HP
4. Dual UP 26-64F (in series), 1/6 HP
5. Dual 008 (in series), 1/12 HP
6. Dual UPS 20-42F at speed 3 (in series), 1/10 HP.

(Note: When centrifugal pumps are connected in series, the head doubles at any given flow. When connected in parallel, the flow doubles at any given head).

From a design standpoint, it is advisable to oversize a pump somewhat (but not excessively) to allow for unaccounted pressure drops and to use single pumps when possible (to reduce costs, complexity, maintenance, etc.). Therefore the 1/12-HP pump number 3 above is a suitable choice. A ball valve and a drainable in-line flow meter located in the collector supply line can be used to adjust the flow rate to 30 gpm.

In the case of 3/4" tubing and fittings, we require a pump that can generate a maximum of about 15 ft water head at 3 gpm water flow (the "start-up" or static head). Referring to the pump curves, we see that the following pumps are capable of 15 ft water head at 3 gpm:

1. Single 009, 1/20 HP
2. Single 008, 1/25 HP
3. Single UP 40-75U, 1/6 HP
4. Single UP 26-96F, 1/12 HP
5. Single UP 26-64F, 1/12 HP
6. Dual 006 (in series), 1/20 HP
7. Dual UPS 20-42F at speed 2 (in series), 1/16 HP

Based on the guidelines mentioned in the preceding case, either pumps 1 or 5 would be suitable. However, since 1 has a lower horsepower rating than 5, pump 1 is more suitable. Again, we would use a valve and drainable flowmeter to adjust the flow to 3 gpm.

The pump selected can contain cast iron "welted" parts since the collector loop is closed and fresh air is not introduced into the system each time the collectors and piping drain to the drain-back tank.

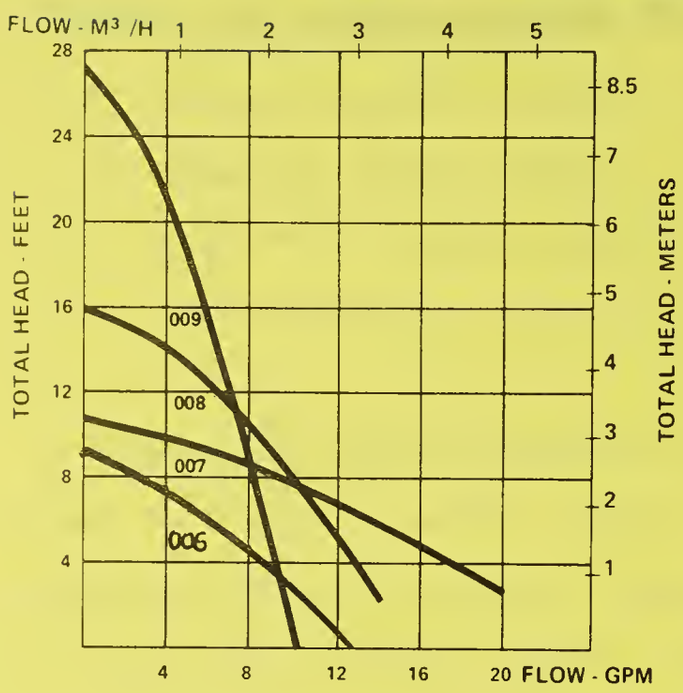
Tube Size Selection

We see that the selection of tube size is a trade-off since either 1/2" or 3/4" will accomplish the task when the pump is correctly selected. In the case of 1/2", the pressure drop, fluid velocity, and pump horsepower ("parasitic energy") are higher than those for the 3/4" case, but the costs of tubing, fittings, pipe insulation, solder, etc. are lower. The decision can be based on an economic analysis of the extra initial cost of the 3/4" case versus lower pumping costs.

In general, the lower velocity (and therefore lower potential for long-term erosion and noise) and lower pumping costs associated with 3/4" tubing relative to 1/2" tubing outweigh the cost advantage of using 1/2" tubing.

Pump Curves for Several Centrifugal

Pumps Typically Used in SDHW Systems



Courtesy of Taco, Inc., Cranston, RI

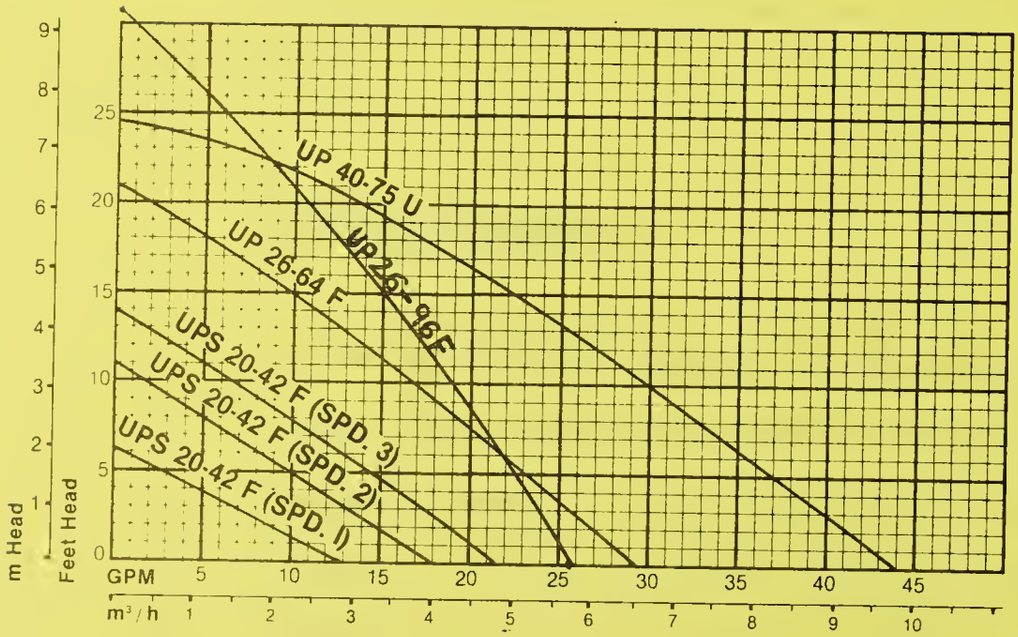
Pump Horsepower Ratings

009 - 1/20 HP

008 - 1/25

007 - 1/25

006 - 1/40



UP 40-75U - 1/6

UP 26-96F - 1/12

UP 26-64F - 1/12

UPS 20-42F

Speed 1 - 1/64

Speed 2 - 1/32

Speed 3 - 1/20

Courtesy of Grundfos, Inc., Clovis, CA

EXAMPLE 2

A closed-loop antifreeze (60% propylene glycol/40% water) SDHW system will be installed in a residence. The system will include two roof-mounted 4' x 8' flat-plate collectors connected in parallel, a 120-gallon solar storage tank, an external counter-flow heat exchanger with double-wall construction, and other system components common to antifreeze-based systems (expansion tank, check valve, air vent, relief valve, etc.).

We wish to size two centrifugal pumps (for solar collector loop and potable water loop) and the copper tubing for each loop.

Data

1. The collector manufacturer recommends that the antifreeze flow rate for each collector is 1.7 gpm.

2. The total length of copper tubing in the solar collector loop is estimated to be 500 ft and includes 15 90^{o} elbows, 5 tees, and a swing check valve.

3. The total length of copper tubing in the potable water loop is estimated to be 10 ft and includes 6 90^{o} elbows.

4. The heat exchanger manufacturer recommends that the potable water flow rate through the exchanger is 8 gpm.

Calculations

Since each collector requires 1.7 gpm and the two collectors are connected in parallel, the total flow rate through the collector loop is 3.4 gpm. The flow rate through the potable water loop is 8 gpm.

In a closed-loop antifreeze system, the solar collector loop is always full of fluid so that a siphon is established immediately upon pump start-up. (In fract, a check valve is required in the solar collector loop so that the antifreeze can not reverse thermosiphon when the solar circulator pump is off.) Therefore, the solar pump does not need to generate sufficient head to lift the fluid to the highest point in the system. The solar pump needs only to overcome the "flowing" or "operating" friction pressure drop or head loss at the desired flow rate (in this case 3.4 gpm). Likewise, the potable water pump needs to overcome the operating pressure drop at the desired flow rate (8 gpm).

Now we find the component pressure drops for the solar collector loop.

Solar Collectors

The collector manufacturer's data sheet gives a pressure drop of 0.08 ft water per collector at 1.7 gpm antifreeze flow. Since the

collectors are in parallel, this is the total pressure drop across the two collectors.

Heat Exchanger

The exchanger manufacturer's data sheet gives a pressure drop of 1.2 ft water at 3.4 gpm antifreeze flow for the solar side of the exchanger.

Copper Tubing and Fittings

We will look at both 1/2" and 3/4" Type L copper tube. Figure 2 (page 12) of the Copper Tube Handbook gives the following pressure drops with a water flow rate of 3.4

1/2" Type L - 9 psi (or 20.79 ft water) per 100 ft of tube

3/4" Type L - 1.7 psi (or 3.93 ft water) per 100 ft of tube.

Figure 2 also shows that the flow velocity for 3.4 gpm is approximately:

1/2" Type L - 4 ft/sec

3/4" Type L - 2 ft/sec.

The "rule of thumb" for maximum velocity is 4 - 6 ft/sec so either 1/2" or 3/4" is satisfactory.

Table 8 (page 13) of the Copper Tube Handbook gives the following equivalent lengths for fittings:

Fitting	Equivalent Length (ft of tube) 1/2"	3/4"
90° elbow	1	1.25
Tee	0.3	0.4
Check valve (use globe valve data)	7.5	10

The total equivalent lengths for the fittings (15 elbows, 5 tees, and a check valve) are"

1/2" - 15 + 1.5 + 7.5 = 24 ft of tube

3/4" - 18.75 + 2.0 + 10 = 30.75 ft of tube.

Now we can get the total pressure drop for the tubing and fittings assuming 3.4 gpm of water flow:

for 1/2" tubing, (50 + 24) ft tubing x $\frac{20.79 \text{ ft water}}{100 \text{ ft tubing}}$ = 15.38 ft water

for 3/4" tubing, (50 + 30.75) ft tubing x $\frac{3.93 \text{ ft water}}{100 \text{ ft tubing}}$ = 3.17 ft water

These tubing and fitting pressure drops are based on water flow. To adjust for the higher viscosity of the 60/40 antifreeze solution, we need to multiply the pressure drop by 1.4 (a correction factor developed from glycol manufacturers' information):

1/2" tubing, 15.38 x 1.4 = 21.53 ft water
3/4" tubing, 3.17 x 1.4 = 4.44 ft water

Total Solar Loop Pressure Drop or Head Loss

Components	1/2" tubing	3/4" tubing
Collector	0.08 ft water	0.08 ft water
Heat Exchanger	1.20	1.20
Tubing & Fittings	21.53	4.44
Total Pressure Drop	22.81 ft water	5.72 ft water

Pump Selection/Solar Loop

For 1/2" tubing, we can select either the 009 or the UP 26-96F pump.

For 3/4" tubing, we can select either the 006 or the UPS 20-42F (speed 2) pump.

In either case we can use a valve and an in-line flowmeter to adjust the solar loop flow rate. Since the solar loop is closed and oxygen-free, the pump can contain cast iron wetted parts.

Potable Water Loop Pressure Drop

Figure 2 (page 12) in the Copper Tube Handbook shows that the velocities of water in 1/2" and 3/4" Type L tubing for 8 gpm flow rate are approximately:

1/2" Type L - 11 ft/sec

3/4" Type L - 5 ft/sec.

Since the velocity in 1/2" tubing exceeds 4 - 6 ft/sec, we must select 3/4" tubing for the potable water loop. The pressure drop for 10 ft of 3/4" tubing and 6 elbows for 8 gpm water flow is:

$$(10 + 7.5) \text{ ft tubing} \times \frac{17.33 \text{ ft water}}{100 \text{ ft tubing}} = 3.03 \text{ ft water}$$

Data from the heat exchanger manufacturer gives a pressure drop of 1.3 ft water at 8 gpm water flow for the water side of the exchanger.

The total pressure drop for the potable water loop is:

$$(3.03 + 1.3) = 4.33 \text{ ft water.}$$

Pump Selection/Potable Water Loop

To achieve 8 gpm water flow at 4.33 ft water head, we can select either the 006 or the UPS 20°-42°F (speed 2) pump. Since the potable water will contain dissolved oxygen, the pump selected must contain bronze or stainless steel wetted parts so that rust will not occur. (Note: The above UPS 20-42F pump has a cast iron body and should not be used for the potable water loop. The UP 25-42SF (not shown on pump curve diagram) has a similar pump curve and bronze body so it can replace the UPS 20°-42°F.)

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- Stainless steel-fitted quality
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- Maintenance free
- Quiet operation

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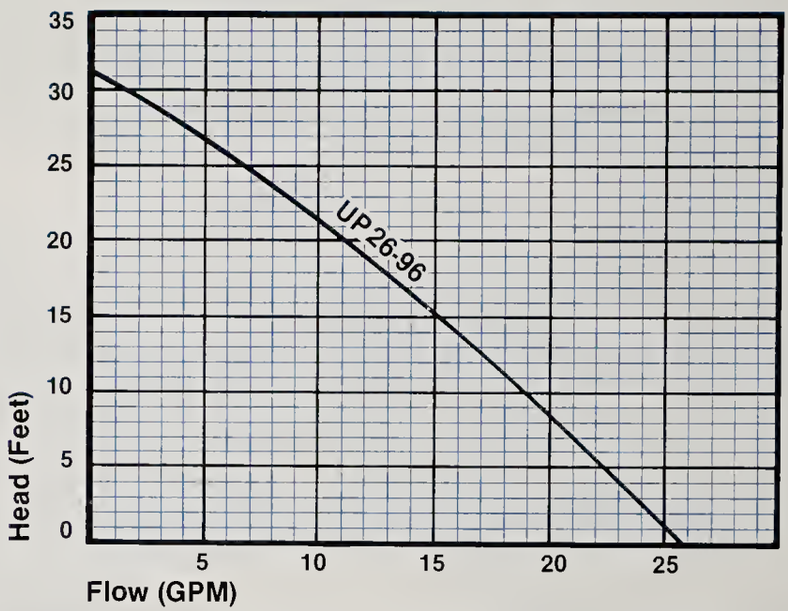

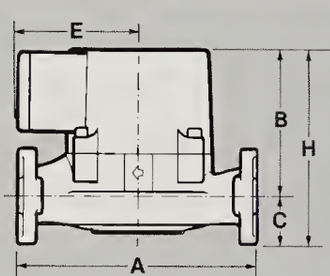

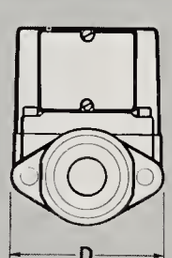

Dimensions and Weights

A	B	C	D	E	H	Net Wt. Lbs.
6-1/2"	5-1/16"	1-5/16"	4-3/16"	3-9/16"	6-3/8"	12

Electrical

Hp	Volts	Amps	Watts	RPM	Capacitor
1/12	115	1.85	205	3310	10 MF/160 V

Accessories

Flange Sets: 3/4", 1", 1-1/4" and 1-1/2"
Bronze Isolation Valves: 3/4", 1" and 1-1/4"

Materials of Construction

Stainless-Steel: Impeller, inlet cone, bearing plate and bearing retainers, rotor can, rotor cladding, rotor impeller, shaft retainer.
Aluminum: Stator housing, terminal box.
Aluminum Oxide Ceramic: Shaft, upper and lower radial bearings.
Metal Impregnated Carbon: Thrust bearing.
Cast Iron or Bronze: Pump housing (volute).
EP (Ethylene propylene rubber): O-ring, gasket, flange gaskets.
Copper: Rotor end caps.

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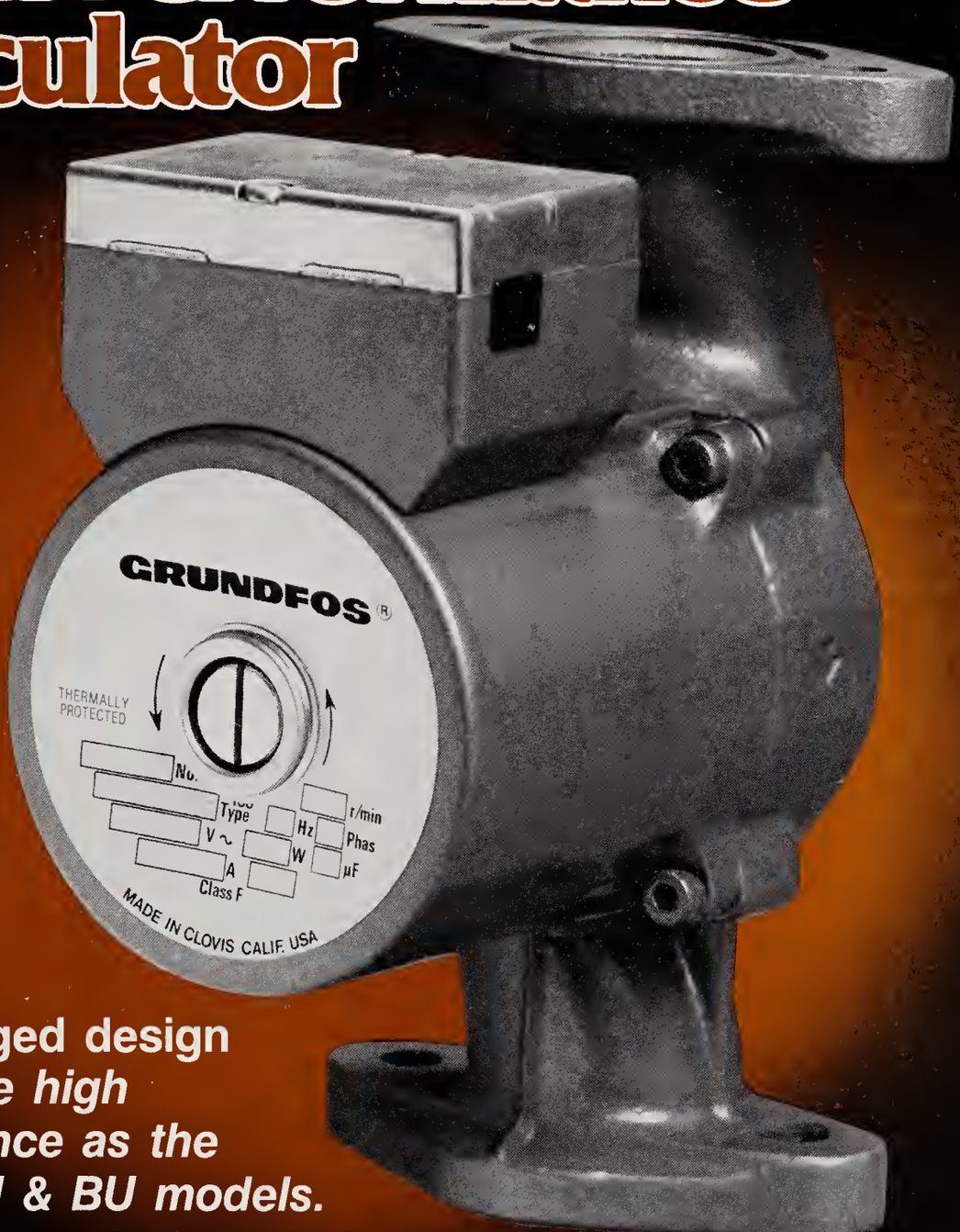

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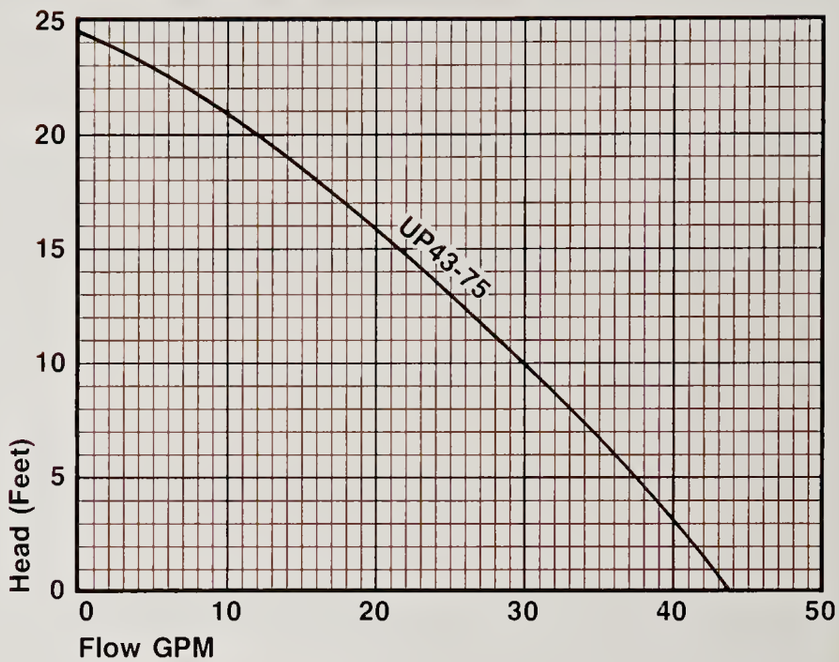


Applications:

UP43-75 models are ideally suited for high flow/moderate head installations, such as closed loop heating systems and multiple zones and solar systems with parallel panel arrangements.

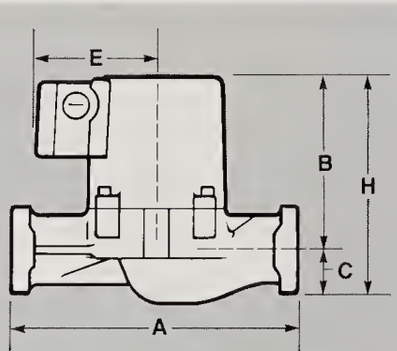
- Flows to 44 gpm and up to 24 feet of head
- Water temperatures up to 230°F
- Maximum system pressures to 142 p.s.i.

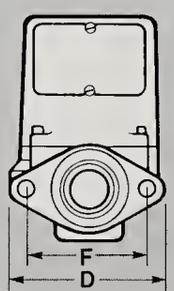
Accessories

Flange Sets: 1-1/2" cast iron or bronze.

Materials of Construction

Stainless Steel: Impeller, inlet cone, bearing plate and bearing retainers, rotor can, rotor cladding, shaft retainer.
Aluminum: Stator housing, terminal box.
Aluminum Oxide Ceramic: Shaft, upper and lower radial bearings.
Metal Impregnated Carbon: Thrust bearing.
Cast Iron or Bronze: Pump housing (volute).
EP (Ethylene propylene rubber): O-ring, gasket, flange gaskets.
Copper: Rotor end caps.





Dimensions and Weights

A	B	C	D	E	F	H	Net Wt. Lbs.
8-9/16	5-3/16	1-7/16	4-3/4	3-5/8	3-7/16	6-5/8	12-3/4

Electrical

HP	Volts	Amps	Watts	RPM	Capacitor
1/6	115	2.15	225	3250	10 MF/160V

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NOTE: For an index of the Figures and Tables contained in this handbook, see page 39.

NOTICE. ***This Handbook has been prepared for the use of journeymen, plumbing and heating contractors, engineers, and others involved in the design or installation of plumbing, heating, air-conditioning and refrigeration systems. It has been compiled from information sources the Copper Development Association Inc. believes to be competent. However, recognizing that each system must be designed and installed to meet the particular circumstances, CDA assumes no responsibility or liability of any kind in connection with this Handbook or its use by any person or organization and makes no representations or warranties of any kind hereby.***

Introduction

Since before the dawn of history—when primitive man first discovered copper—the red metal has constantly served the advancement of civilization. Archeologists, probing ancient ruins, have discovered that this enduring metal was a great boon to many peoples. Tools for handicraft and agriculture, weapons for hunting, and articles for decorative and household uses were wrought from copper by early civilizations. The craftsmen who built the great pyramid for the Egyptian Pharaoh, Cheops, fashioned copper pipe to convey water to the royal bath. A remnant of this pipe was unearthed some years ago, still in usable condition, a testimonial to copper's durability and resistance to corrosion.

Modern man, recognizing that no material is superior to copper for conveying water, has reestablished it as the prime material for such purposes. Years of trouble-free service in installations here and abroad have gained a new reputation for copper piping in its modern form—light, strong, corrosion resistant tube. It serves all kinds of buildings: single-family homes, high rise apartments, and industrial, commercial, and office buildings.

Today, copper tube for the plumbing, heating, and air conditioning industries is available in drawn and annealed tempers (referred to in the trades as "hard" and "soft") and a wide range of diameters and wall thicknesses. Readily available fittings serve every design application. Joints are simple, reliable, and economical to make—additional reasons for selecting copper tube.

Today, nearly 5,000 years after Cheops, copper developments continue as the industry pioneers broader uses for copper tube in engineered plumbing systems for new and retrofitted residential, industrial, and commercial installations.

Standard tubes

LONG LASTING COPPER TUBE is a favorite choice in plumbing, heating, cooling, and other systems applications. In the United States, it is manufactured to meet the requirements of specifications established by the American Society for Testing and Materials (ASTM*). All tube supplied to these ASTM standards is a minimum of 99.90 percent pure copper. The copper customarily used for tubes supplied to these specifications is deoxidized with phosphorus and referred to as Copper No. 122 or DHP Copper. Other coppers are also sometimes used.

Types of copper tube

There are two principal classes of copper tube. The first is commonly referred to as *plumbing tube* and includes Types K, L, M, and DWV. The second is ACR tube, for air conditioning and refrigeration field service.

These classes and types of tube are commercially available in the tempers and lengths described in Table 1.

Types K, L, M, and DWV are designated by ASTM standard sizes, with the outside diameter always ⅛-inch larger than the standard size. Each type (K, L, M, and DWV) represents a series of sizes with different wall thicknesses. The inside diameters depend on tube size and wall thickness. All four types are available in drawn temper in straight lengths ordinarily 20 feet long. Types K, L and M are available also in annealed temper in 20-ft straight lengths or in long coils in sizes from ¼-inch to 2-inch.

Copper tube for air conditioning and refrigeration field service (ACR tube) is designated by its actual outside diameter. It is available in soft annealed coils or hard-drawn lengths. It is intended for use in the field with special fittings for connections, repairs, and alterations in air conditioning and refrigeration installations.

In the piping trades, drawn tube is often referred to as "hard" tube, and annealed tube as "soft" tube. Drawn tube is also furnished in a "bending temper." This light-drawn temper of intermediate strength and hardness may be specified for applications requiring bending. Tube in the hard temper condition can be joined by soldering or brazing, using capillary fittings, or by welding. Tube in the bending and soft tempers can be joined by the same techniques and also by the use of flare-type compression fittings. It is also possible to expand the end of one tube so that it can be joined to another by soldering or brazing without a capillary fitting — a procedure that can be efficient and economical in many installations.

*American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103

table 1 Standard copper plumbing tube
Types — Tempers — Lengths

COMMERCIALLY AVAILABLE LENGTHS		
TUBE	**DRAWN**	**ANNEALED**
Type K	Straight Lengths: Up to 8-inch diameter — 20 ft 10-inch diameter — 18 ft 12-inch diameter — 12 ft	Straight Lengths: Up to 8-inch diameter — 20 ft 10-inch diameter — 18 ft 12-inch diameter — 12 ft Coils: Up to 1-inch diameter — 60 ft 100 ft 1¼ and 1½-inch diameter — 60 ft 2-inch diameter — 40 ft 45 ft
Type L	Straight Lengths: Up to 10-inch diameter — 20 ft 12-inch diameter — 18 ft	Straight Lengths: Up to 10-inch diameter — 20 ft 12-inch diameter — 18 ft Coils: Up to 1-inch diameter — 60 ft 100 ft 1¼ and 1½-inch diameter — 60 ft 2-inch diameter — 40 ft 45 ft
Type M	Straight Lengths: All diameters — 20 ft	Straight Lengths: Up to 12-inch diameter — 20 ft Coils: Up to 1-inch diameter — 60 ft 100 ft 1¼ and 1½-inch diameter — 60 ft 2-inch diameter — 40 ft 45 ft
DWV	Straight Lengths: All diameters — 20 ft	Not available — —
ACR	Straight Lengths*: — 20 ft	Coils*: — 50 ft

*See Table 3 for availability of diameters in drawn and annealed tempers.

table 2 Physical characteristics of copper tube
Types K, L, M and DWV

Size, inches	Nominal Dimensions, inches			Calculated Values, Based on Nominal Dimensions			
	Outside Diameter	Inside Diameter	Wall Thickness	Cross Sectional Area of Bore, sq inches	External Surface, sq ft per lin ft	Internal Surface, sq ft per lin ft	Weight, pounds per lin ft
TYPE K							
¼	.375	.305	.035	.073	.098	.080	0.145
⅜	.500	.402	.049	.127	.131	.105	0.269
½	.625	.527	.049	.218	.164	.138	0.344
⅝	.750	.652	.049	.334	.196	.171	0.418
¾	.875	.745	.065	.436	.229	.195	0.641
1	1.125	.995	.065	.778	.294	.261	0.839
1¼	1.375	1.245	.065	1.22	.360	.326	1.04
1½	1.625	1.481	.072	1.72	.425	.388	1.36
2	2.125	1.959	.083	3.01	.556	.513	2.06
2½	2.625	2.435	.095	4.66	.687	.638	2.93
3	3.125	2.907	.109	6.64	.818	.761	4.00
3½	3.625	3.385	.120	9.00	.949	.886	5.12
4	4.125	3.857	.134	11.7	1.08	1.01	6.51
5	5.125	4.805	.160	18.1	1.34	1.26	9.67
6	6.125	5.741	.192	25.9	1.60	1.50	13.9
8	8.125	7.583	.271	45.2	2.13	1.98	25.9
10	10.125	9.449	.338	70.1	2.65	2.47	40.3
12	12.125	11.315	.405	101.	3.17	2.96	57.8
TYPE L							
¼	.375	.315	.030	.078	.098	.082	0.126
⅜	.500	.430	.035	.145	.131	.113	0.198
½	.625	.545	.040	.233	.164	.143	0.285
⅝	.750	.666	.042	.348	.196	.174	0.362
¾	.875	.785	.045	.484	.229	.206	0.455
1	1.125	1.025	.050	.825	.294	.268	0.655
1¼	1.375	1.265	.055	1.26	.360	.331	0.884
1½	1.625	1.505	.060	1.78	.425	.394	1.14
2	2.125	1.985	.070	3.09	.556	.520	1.75
2½	2.625	2.465	.080	4.77	.687	.645	2.48
3	3.125	2.945	.090	6.81	.818	.771	3.33
3½	3.625	3.425	.100	9.21	.949	.897	4.29
4	4.125	3.905	.110	12.0	1.08	1.02	5.38
5	5.125	4.875	.125	18.7	1.34	1.28	7.61
6	6.125	5.845	.140	26.8	1.60	1.53	10.2
8	8.125	7.725	.200	46.9	2.13	2.02	19.3
10	10.125	9.625	.250	72.8	2.65	2.53	30.1
12	12.125	11.565	.280	105.	3.17	3.03	40.4

table 2 (cont'd)

TYPE M

Size, inches	Nominal Dimensions, inches			Calculated Values, Based on Nominal Dimensions			
	Outside Diameter	Inside Diameter	Wall Thickness	Cross Sectional Area of Bore, sq inches	External Surface, sq ft per lin ft	Internal Surface, sq ft per lin ft	Weight, pounds per lin ft
⅜	.500	.450	.025	.159	.131	.118	0.145
½	.625	.569	.028	.254	.164	.149	0.204
¾	.875	.811	.032	.517	.229	.212	0.328
1	1.125	1.055	.035	.874	.294	.276	0.465
1¼	1.375	1.291	.042	1.31	.360	.338	0.682
1½	1.625	1.527	.049	1.83	.425	.400	0.940
2	2.125	2.009	.058	3.17	.556	.526	1.46
2½	2.625	2.495	.065	4.89	.687	.653	2.03
3	3.125	2.981	.072	6.98	.818	.780	2.68
3½	3.625	3.459	.083	9.40	.949	.906	3.58
4	4.125	3.935	.095	12.2	1.08	1.03	4.66
5	5.125	4.907	.109	18.9	1.34	1.28	6.66
6	6.125	5.881	.122	27.2	1.60	1.54	8.92
8	8.125	7.785	.170	47.6	2.13	2.04	16.5
10	10.125	9.701	.212	73.9	2.65	2.54	25.6
12	12.125	11.617	.254	106.	3.17	3.04	36.7

TYPE DWV

1¼	1.375	1.295	.040	1.32	.360	.339	.65
1½	1.625	1.541	.042	1.87	.425	.403	.81
2	2.125	2.041	.042	3.27	.556	.534	1.07
3	3.125	3.030	.045	7.21	.818	.793	1.69
4	4.125	4.009	.058	12.6	1.08	1.05	2.87
5	5.125	4.981	.072	19.5	1.34	1.30	4.43
6	6.125	5.959	.083	27.9	1.60	1.56	6.10
8	8.125	7.907	.109	49.1	2.13	2.07	10.6

Properties

Copper tubes, Types K, L, and M are made according to ASTM Standard Specification B88; DWV is made to ASTM B306. The dimensions and other physical characteristics of these four types of tube are given in Table 2. All four types are used for both pressure and non-pressure applications within the range of their respective safe working pressures as described on pages 15 and 17.

Seamless ACR tube is made to ASTM Standard Specification B280. The dimensions and physical characteristics of this tube are given in Table 3.

table 3 Physical characteristics of copper tube

Air conditioning and refrigeration tube for field service

Size, inches	Nominal Dimensions, inches			Calculated Values, Based on Nominal Dimensions			
	Outside Diameter	Inside Diameter	Wall Thickness	Cross Sectional Area of Bore, sq inches	External Surface, sq ft per lin ft	Internal Surface, sq ft per lin ft	pounds per lin ft
1/8	**.125**	**.065**	**.030**	**.00332**	**.0327**	**.0170**	**.0347**
3/16	**.188**	**.128**	**.030**	**.0129**	**.0492**	**.0335**	**.0577**
1/4	**.250**	**.190**	**.030**	**.0284**	**.0655**	**.0497**	**.0804**
5/16	**.312**	**.248**	**.032**	**.0483**	**.0817**	**.0649**	**.109**
3/8	*.375*	*.315*	*.030*	*.0780*	*.0982*	*.0821*	*.126*
3/8	**.375**	**.311**	**.032**	**.0760**	**.0982**	**.0814**	**.134**
1/2	**.500**	**.436**	**.032**	**.149**	**.131**	**.114**	**.182**
1/2	*.500*	*.430*	*.035*	*.145*	*.131*	*.113*	*.198*
5/8	**.625**	**.555**	**.035**	**.242**	**.164**	**.145**	**.251**
5/8	*.625*	*.545*	*.040*	*.233*	*.164*	*.143*	*.285*
3/4	.750	.666	.042	.348	.196	.174	.362
7/8	.875	.785	.045	.484	.229	.206	.455
1 1/8	1.125	1.025	.050	.825	.294	.268	.655
1 3/8	1.375	1.265	.055	1.26	.360	.331	.884
1 5/8	*1.625*	*1.505*	*.060*	*1.78*	*.425*	*.394*	*1.14*
2 1/8	*2.125*	*1.985*	*.070*	*3.09*	*.556*	*.520*	*1.75*
2 5/8	*2.625*	*2.465*	*.080*	*4.77*	*.687*	*.645*	*2.48*
3 1/8	*3.125*	*2.945*	*.090*	*6.81*	*.818*	*.771*	*3.33*
3 5/8	*3.625*	*3.425*	*.100*	*9.21*	*.949*	*.897*	*4.29*
4 1/8	*4.125*	*3.905*	*.110*	*12.0*	*1.08*	*1.02*	*5.38*

NOTE: Sizes shown in bold face type are available in annealed temper only; sizes shown in italics are available in hard temper only, all others in both.

Color identification of copper tube

Hard temper copper tube in straight lengths is marked in accord with the governing specifications, in distinguishing colors which indicate the type, with the type, the name or trademark of the manufacturer, and the country of origin. Incised markings are sometimes required by specifications. Soft temper tube is not color marked in this way, but the distinguishing colors are used for identification on cartons and shipping tags.

The colors are:

Green — Type K Copper Tube

Blue — Type L Copper Tube and straight lengths of Copper ACR Tube

Red — Type M Copper Tube

Yellow — Type DWV Copper Tube

Selecting the right tube for the job

Advantages of copper tube

High-strength, corrosion resistant, smooth-bore copper plumbing tube is the leading choice, by far, of modern contractors for plumbing and heating installations in all kinds of residential and commercial buildings. There are seven primary reasons for this popularity:

1. Copper resists corrosion. Excellent resistance to corrosion and scaling assures long trouble-free service with copper which, in turn, means satisfied customers.

2. Copper is lightweight. Copper tube does not require the heavy thickness of ferrous or threaded pipes of the same internal diameter. This means copper costs less to transport, handles more easily and, when installed, takes less space.

3. Copper is formable. Because copper tube can be readily bent and formed, it is frequently possible to eliminate elbows and joints. Smooth bends permit the tube to follow contours and corners of any angle. With soft temper tube, particularly when used for renovation or modernization projects, much less wall and ceiling space is needed.

4. Copper is easy to join. Copper tube can be joined with capillary fittings. These fittings save material and make smooth, neat, strong and leak-proof joints. No extra thickness or weight is necessary to compensate for material removed by threading.

5. Copper is safe. Copper tube will not burn or support combustion and decompose to toxic gases. Therefore, it will not carry fire through floors, walls and ceilings. And no volatile compounds are required for installation.

6. Copper is dependable. Copper tube is manufactured to well-defined composition standards and marked with permanent identification so you know exactly what it is and who made it.

7. Copper is economical. The combination of easy handling, forming, and joining permits savings in installation time, material and overall costs. Long-term performance reliability and wide code acceptance make copper the ideal cost-effective piping material.

Recommendations for various applications

It is the designer's responsibility to determine the type of copper tube to be used in a particular application. Strength, formability, and other mechanical factors frequently determine the choice. Sometimes building or plumbing codes govern what types may be used. When a choice can be made, it is helpful to know which type of copper tube has served and will serve successfully and economically in the following applications:

Underground Water Services — Use Type M for straight lengths joined with fittings, and Type L soft temper where coils are more convenient.

Water Distribution Systems — Use Type M for above and below ground.

Chilled Water Mains — Use Type M for sizes up to 1 inch and Type DWV for sizes of 1¼ inch and larger.

Drainage and Vent Systems — Use Type DWV for above and below ground, waste, soil, and vent lines, roof drainage, building drains, and building sewers.

Heating — For radiant panel and hydronic heating, and for snow melting systems, use Type L soft temper where the coils are formed in place or prefabricated, Type M where straight lengths joined with fittings are used. For hot-water heating and low-pressure steam, use Type M for sizes up to 1¼ inch and Type DWV for sizes of 1¼ inch and larger. For condensate return lines, Type L is successfully used.

Solar Heating — See "Heating" section above. For information on solar installation and on solar collectors, write CDA. (See also Page 22.)

Fuel Oil and Underground Gas Services — Use copper tube in accord with local codes.

Oxygen Systems — Use Type L or K, suitably cleaned for oxygen service per NFPA* Publication No. 56F, "Non-flammable Medical Gas Systems."

*National Fire Protection Association, 470 Atlantic Avenue, Boston, Massachusetts 02210

Design and installation data

Pressure system sizing

Designing a copper tube water supply system is a matter of determining the minimum tube size for each part of the total system by balancing the interrelationships of six primary design considerations:

1. Available main pressure
2. Pressure required at individual fixtures
3. Static pressure losses due to height
4. Water demand (gallons per minute) in the total system and in each of its parts
5. Pressure losses due to the friction of water flow in the tube
6. Velocity limitations based on noise and erosion.

Design and sizing are influenced by codes and must always conform to applicable codes. But in the final analysis design must also reflect judgement and the results of engineering calculations. Many codes, especially the model codes*, include design data and guidelines for sizing water distribution systems and also include examples showing how the data and guidelines are used to size a system. Detailed guidelines are also to be found in two publications ‡of the National Bureau of Standards.

Small Systems — Distribution systems for single-family houses can be sized easily on the basis of experience and any applicable code requirements, as can other similar small installations. Detailed study of the six design considerations above is not necessary in such cases. The size of the short branches to individual fixtures can be determined by reference to Table 4**. In general, the mains servicing these fixture branches can then be sized as follows:

- Up to three ⅜-inch branches can be served by a ½-inch main.
- Up to three ½-inch branches (or up to five ⅜-inch branches) can be served by a ¾-inch main.
- Up to three ¾-inch branches (or correspondingly more ½-inch or ⅜-inch branches) can be served by a 1-inch main.

Generous sizing within these limits will give good design and the best service. Working to minimum sizing within these guidelines will give an adequate system most of the time,

*e.g.: *BOCA Basic Plumbing Code,* Building Officials and Code Administrators International, Inc., Chicago, Illinois; *National Standard Plumbing Code,* National Association of Plumbing-Heating-Cooling Contractors, Washington, D.C.; *Southern Standard Plumbing Code,* Southern Building Code Congress, Birmingham, Alabama; *Uniform Plumbing Code,* International Association of Plumbing & Mechanical Officials, Los Angeles, California.

‡*Plumbing Manual,* Report BMS66, National Bureau of Standards, Washington, D.C. (1940). *Water Distribution Systems for Buildings* Report BMS79, National Bureau of Standards, Washington, D.C. (1941).

**Table 4 also applies to large systems.

table 4 Examples of minimum copper tube sizes for short branch connections to fixtures

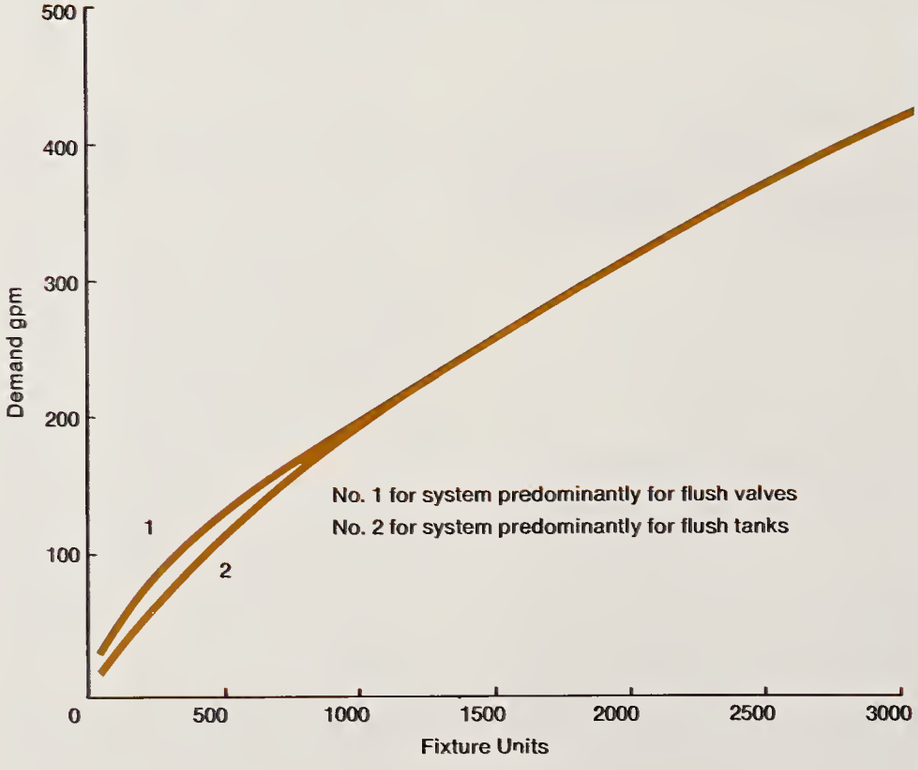
Fixture	Copper Tube Size, inches
Drinking Fountain	⅜
Lavatory	⅜
Water Closet (tank type)	⅜
Bathtub	½
Dishwasher (home)	½
Kitchen Sink (home)	½
Laundry Tray	½
Service Sink	½
Shower Head	½
Sill Cock, Hose Bibb, Wall Hydrant	½
Urinal (tank type)	½
Washing Machine (home)	½
Kitchen Sink (commercial)	¾
Urinal (flush valve)	¾
Water Closet (flush valve)	1

table 5 Typical fixture unit values

Fixture	Fixture Unit Values*	
	Private Use	Public Use
Bathtub (with or without shower)	2	4
Dishwasher (home)	2	–
Drinking Fountain	1	2
Hospital Sink (flushing rim)	–	10
Kitchen Sink	2	4
Lavatory	1	2
Laundry Tray	2	4
Service Sink	2	4
Shower (separate, each head)	2	4
Urinal (tank)	–	3
Urinal (flush valve)	–	5
Washing Machine	2	4
Washup Sink (circular spray)	–	4
Water Closet (tank)	3	5
Water Closet (flush valve)	6	10
Bathroom Group (tank)	6	–
Bathroom Group (flush valve)	8	–

*Values are for total demand, hot and cold. For either hot or cold demand by itself, use 75% of the total fixture unit value. For details, see "Water Demand," page 13.

figure 1 Water-demand estimating curve



depending on available main pressure and the probability of simultaneous use of fixtures. The water distribution system in many single-family homes with 2½ baths, for example, has been completely plumbed with copper tube of ¾-inch size and smaller.

The sizing of more complex distribution systems requires detailed analysis of each of the size design considerations listed above.

Pressure Considerations—The water service pressure at the point where the building distribution system (or segment or zone thereof) begins depends either on the local main pressure, the local code, the pressure desired by the system designer—or on a combination of these. In any case, it should not be higher than about 80 psi.

Some of this pressure is lost immediately in flow through the water meter, if there is one. The amount of loss in a disk-type meter depends on flow rate and tube size. Design curves and tables showing these relationships appear in most model codes and are available from meter manufacturers. As a practical example, a loss of 10 psi will occur in the meter for each of the following combinations of flow and tube size at the meter:

Tube Size, Inches	Approx. Flow Rate, gpm
¾	22
1	35
1½	63
2	100
3	190
4	320
6	630

The pressure remaining after the loss going through the meter is then the available pressure to distribute the water to the various fixtures throughout the building. At each fixture a minimum pressure of 8 psi

should be available for it to function properly — except that some fixtures require a higher minimum pressure for proper function, for example:

Flush valve for blow-out and syphon-jet closets . . . . . 25 psi

Flush valves for water closets and urinals . . . . . 15 psi

Sill cocks, hose bibbs and wall hydrants . . . . . 10 psi

Local codes and practices may be somewhat different from the above, of course.

Some of the main pressure will also be lost in lifting the water to the highest fixture in the system. To account for this, multiply the elevation of the highest fixture, in feet, by the factor 0.434. This will give the pressure needed to raise the water to that level. The height difference is measured starting at the meter, or at whatever other point represents the start of the system or the segment or zone being considered. For example, a difference of height of 30 feet reduces the available pressure by 13 psi (30 x 0.434 = 13.02).

table 6 Relationship of fixture units to water demand (Based on figure 1)

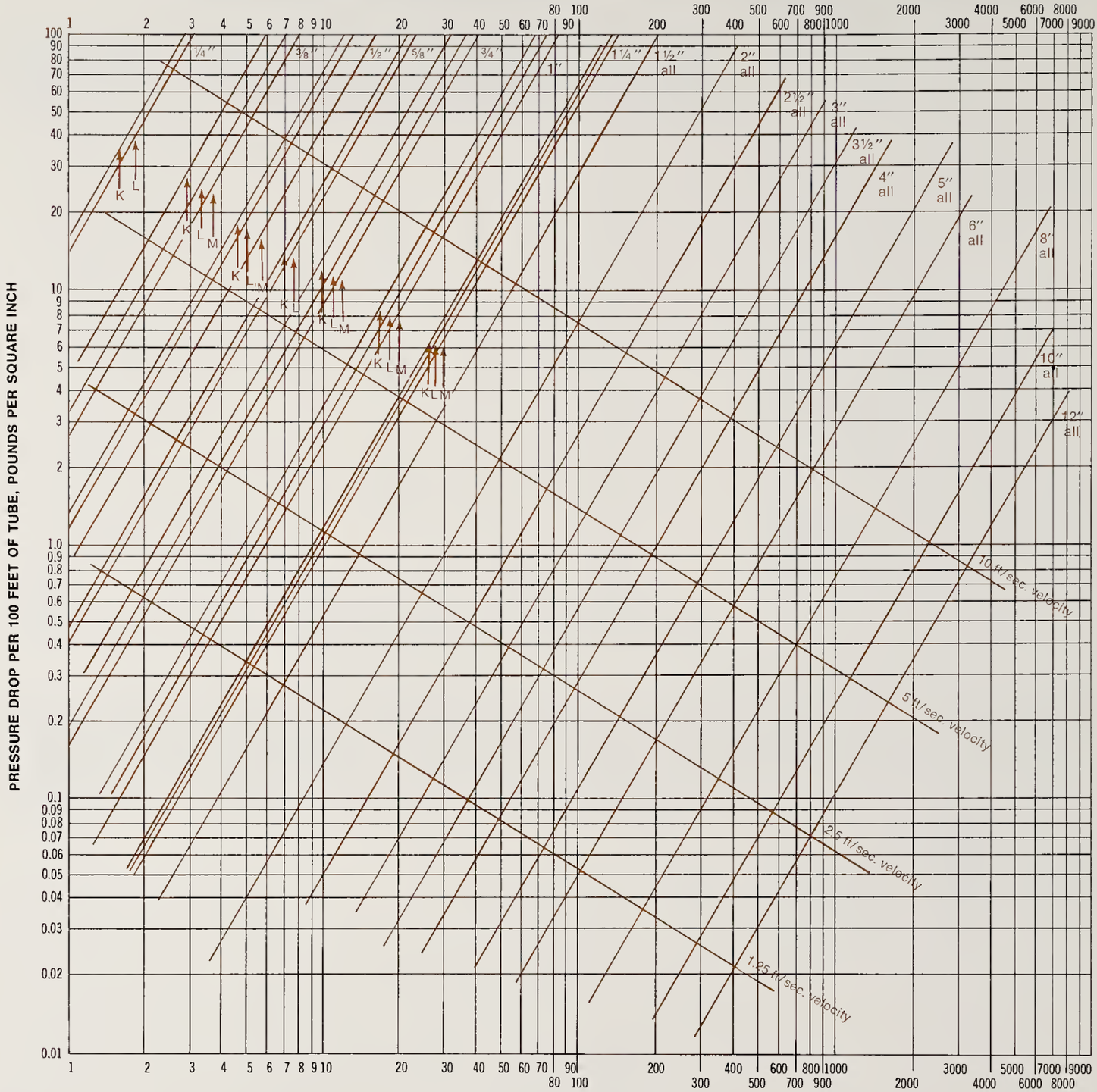
Total Fixture Units	Water Demand, gpm	
	Tank Type WC's	Flush Valve WC's
5	4	22
10	8	27
20	14	35
30	20	42
40	24	46
50	28	51
75	37	60
100	43	68
200	65	91
300	85	110
400	106	127
500	124	142
600	143	157
700	161	170
800	178	183
1000	208	
1500	270	
2000	327	
3000	435	

table 7 Pressure loss due to friction in type M copper tube (Based on figure 2)

Flow, gpm	Pressure Loss per 100 Feet of Tube, psi											
	Standard Type M Tube Size — inches											
	⅜	½	¾	1	1¼	1½	2	2½	3	4	5	6
1	2.5	0.8	0.2									
2	8.5	2.8	0.5	0.2								
3	17.3	5.7	1.0	0.3	0.1							
4	28.6	9.4	1.8	0.5	0.2							
5	42.2	13.8	2.6	0.7	0.3	0.1						
10		**46.6**	8.6	2.5	0.9	0.4	0.1					
15			17.6	5.0	1.9	0.9	0.2					
20			**29.1**	8.4	3.2	1.4	0.4	0.1				
25				12.3	4.7	2.1	0.6	0.2				
30				**17.0**	6.5	2.9	0.8	0.3	0.1			
35					8.5	3.8	1.0	0.4	0.2			
40					11.0	4.9	1.3	0.5	0.2			
45					**13.6**	6.1	1.6	0.6	0.2			
50						7.3	2.0	0.7	0.3			
60						10.2	2.7	1.0	0.4			
70						**13.5**	3.6	1.2	0.5	0.1		
80							4.6	1.6	0.7	0.2		
90							5.7	2.0	0.9	0.2		
100							**7.5**	2.7	1.0	0.3	0.1	
200								**8.5**	3.6	1.0	0.3	0.1
300									**8.0**	2.0	0.7	0.3
400										**3.3**	1.2	0.5
500											1.7	0.7
750											**3.6**	1.5
1000												**2.5**

NOTE: Numbers in bold face correspond to flow velocities of just over 10 ft per sec.

figure 2 Pressure loss and velocity relationships for water flowing in copper tube



NOTE: Fluid velocities in excess of 5 to 8 ft/sec. are not usually recommended

Water Demand — Each fixture in the system represents a certain demand for water. Some examples of approximate water demand in gallons per minute (gpm) of flow, are:

	gpm
Drinking fountain	0.75
Lavatory faucet	2
Lavatory faucet, self closing	2.5
Sink faucet, WC tank ball cock	3
Bathtub faucet, shower head, laundry tub faucet	4
Sill cock, hose bibb, wall hydrant	5
Flush valve (depending on design)	15–35

Adding up numbers like these to cover all the fixtures in an entire building distribution system would give the total demand for water usage, in gallons per minute, if all of the fixtures were operating and flowing at the same time — which of course does not happen. A reasonable estimate of demand is one based on the extent to which various fixtures in the building might actually be used simultaneously. Researchers at the National Bureau of Standards studied this question some years ago. They applied probability theory and field observations to the real-life problem of simultaneous usage of plumbing fixtures.

The result was a system for estimating total water demand which is based on reasonable assumptions about the likelihood of simultaneous usage of fixtures. Out of this study came the concept of "fixture units." Each type of fixture is assigned a fixture unit value which reflects (1) its demand for water, that is, the flow rate into the fixture when it is used, (2) the average time duration of flow when the fixture is used, and (3) the frequency with which the fixture is likely to be used. The results are shown in Table 5. These values show the *relative* extent to which different types of fixtures put a demand on a water distribution system, their relative "loading" of the system. Totalling the fixture unit values for all the fixtures in a system, or for any part of the distribution system, gives a measure of the load the combined fixtures impose on the plumbing distribution and supply system.

This fixture unit total is then translated into expected maximum water demand (gpm of flow) by using the demand curve shown in Figure 1, (P. 10). Some numerical values from Figure 1 are shown in Table 6, as an example.

The demand calculation just described applies to fixtures that are used *intermittently*. To this must be added the actual demand in gpm for any fixtures which are designed to run continuously when they are in use; for example, air conditioning systems, lawn sprinkler systems, hose bibbs, etc.

Pressure Losses Due To Friction — The pressure available to move the water through the distribution system (or a part thereof) is the main pressure minus: (1) the pressure loss in the meter, (2) the pressure needed to lift water to the highest fixture (static pressure loss) and (3) the pressure needed at the fixtures themselves*. This remaining available pressure must be adequate to overcome the pressure losses due to friction during flow of the total demand (intermittent plus continuous fixtures) through the distribution system and its various parts. The final operation then is to select the tube sizes in accordance with the pressure losses due to friction. In actual practice the design operation may involve repeating the steps in the design process to readjust pressure, velocity, and size to achieve the best balance of main pressure, tube size, velocity and available pressure at the fixtures for the design flow required in the various parts of the system.

Figure 2 shows the relationship between flow, pressure loss due to friction, velocity and tube size for copper water tube types K, L and M. These are the data required to complete the sizing calculations. Table 7 shows as an example some values for Type M tube taken from the curves in Figure 2. For tube sizes above about 1¼ inch there is virtually no difference between the three types of tube in terms of pressure loss. This is because the differences in cross sectional area between the three types become insignificant as the tube size increases. In fact, for this reason, Figure 2 can be used for DWV tube as well.

The pressure loss values in Figure 2 and Table 7 are given in terms of 100 feet of tube. Tube segments less than 100 feet long cause pressure losses proportionately less than the 100-foot values. For 30 feet of tube, for example, the 100-foot value would be multiplied by 0.3. In measuring the length of a system or of any of its parts, the total length of tube must be measured and, for close estimates, an additional amount must be added on as an allowance for the extra friction losses that occur as a result of valves and fittings

*In any actual system there may also sometimes be other specific sources of pressure loss that must be considered at this point: e.g. taps, backflow preventers, filters, etc.

table 8 Allowance for friction loss in valves and fittings expressed as equivalent length of tube

Fitting Size, inches	Equivalent Length of Tube, feet						
	Standard Ells		90° Tee		Coupling	Gate Valve	Globe Valve
	90°	45°	Side Branch	Straight Run			
⅜	0.5	0.3	0.75	0.15	0.15	0.1	4
½	1	0.6	1.5	0.3	0.3	0.2	7.5
¾	1.25	0.75	2	0.4	0.4	0.25	10
1	1.5	1.0	2.5	0.45	0.45	0.3	12.5
1¼	2	1.2	3	0.6	0.6	0.4	18
1½	2.5	1.5	3.5	0.8	0.8	0.5	23
2	3.5	2	5	1	1	0.7	28
2½	4	2.5	6	1.3	1.3	0.8	33
3	5	3	7.5	1.5	1.5	1	40
3½	6	3.5	9	1.8	1.8	1.2	50
4	7	4	10.5	2	2	1.4	63
5	9	5	13	2.5	2.5	1.7	70
6	10	6	15	3	3	2	84

NOTE: Allowances are for streamlined soldered fittings and recessed threaded fittings. For threaded fittings, double the allowances shown in the table.

table 9 Rated internal working pressures for copper tube
Types K, L, M and DWV

Size, inches	Rated Internal Working Pressures, psi							
	Type K		Type L		Type M		DWV	
	Annealed	Drawn	Annealed	Drawn	Annealed	Drawn	Annealed	Drawn
	Service Temperature up to 150F (S=5,100 psi, annealed; 9,000 psi, drawn)							
¼	900	1595	810	1350	—	—	—	—
⅜	990	1745	675	1195	475	840	—	—
½	780	1375	625	1105	430	760	—	—
⅝	640	1135	545	965	—	—	—	—
¾	750	1315	495	875	350	610	—	—
1	575	1010	440	770	295	515	—	—
1¼	465	820	385	680	295	515	275	490
1½	435	765	355	630	290	510	245	435
2	380	665	315	555	300	450	185	325
2½	355	520	295	520	235	410	—	—
3	340	605	275	490	220	385	135	240
3½	325	570	270	470	215	385	—	—
4	315	555	255	450	215	380	130	225
5	305	540	235	410	205	355	130	225
6	305	540	215	385	190	335	130	225
8	325	580	240	420	200	350	125	220
10	330	585	240	425	205	355	—	—
12	330	585	225	395	205	360	—	—
	Service Temperature 200 F (S=4,800 psi, annealed; 9,000 psi drawn)							
¼	855	1595	720	1350	—	—	—	—
⅜	935	1745	635	1195	450	840	—	—
½	735	1375	590	1105	410	760	—	—
⅝	610	1135	515	965	—	—	—	—
¾	705	1315	470	875	325	610	—	—
1	545	1010	410	770	275	515	—	—
1¼	440	820	365	680	275	515	260	470
1½	410	765	340	630	275	510	235	420
2	355	665	300	555	240	450	175	315
2½	330	520	275	520	220	410	—	—
3	320	605	260	490	210	385	125	230
3½	305	570	255	470	210	385	—	—
4	300	555	240	450	205	380	120	220
5	290	540	220	410	190	355	120	220
6	290	540	210	385	180	335	120	215
8	310	580	225	420	190	350	120	210
10	315	585	225	425	190	355	—	—
12	315	585	210	395	190	360	—	—
	Service Temperature 300F (S=4,700 psi, annealed; 8,700 psi, drawn)							
¼	830	1540	705	1305	—	—	—	—
⅜	910	1690	625	1155	435	815	—	—
½	720	1330	580	1065	395	735	—	—
⅝	590	1095	505	930	—	—	—	—
¾	685	1275	455	845	320	590	—	—
1	525	980	405	745	270	500	—	—
1¼	430	795	355	660	270	500	260	470
1½	400	740	330	610	270	490	225	420
2	335	645	290	540	235	435	170	315
2½	325	600	275	500	215	400	—	—
3	315	585	255	470	200	375	125	230
3½	295	550	245	455	200	370	—	—
4	290	535	235	435	195	370	120	220
5	280	520	215	395	190	345	120	220
6	280	525	200	370	175	325	120	215
8	300	560	220	405	185	340	115	210
10	305	565	220	410	190	345	—	—
12	305	565	205	385	190	345	—	—

table 9 (cont'd)

Size, inches	Rated Internal Working Pressures, psi							
	Type K		Type L		Type M		DWV	
	Annealed	Drawn	Annealed	Drawn	Annealed	Drawn	Annealed	Drawn
	Service Temperature 400F (S = 3,000 psi, annealed; 8,200 psi, drawn)							
¼	530	1440	450	1475	—	—	—	—
⅜	580	1590	395	1295	280	770	—	—
½	455	1245	365	1195	250	690	—	—
⅝	380	1035	325	1065	—	—	—	—
¾	440	1195	290	785	205	560	—	—
1	335	920	260	705	175	475	—	—
1¼	275	755	230	625	175	475	160	445
1½	260	705	210	575	170	460	145	395
2	220	605	185	510	150	410	110	295
2½	205	560	175	475	140	375	—	—
3	205	560	160	445	130	425	80	215
3½	190	525	155	425	125	345	—	—
4	185	510	150	410	125	345	80	215
5	180	490	140	375	120	330	80	215
6	180	490	125	345	115	310	70	195
8	190	525	140	375	120	330	70	195
10	190	525	145	475	120	330	—	—
12	200	540	130	425	120	330	—	—

in the line. Table 8 shows these allowances for various sizes and types of valves and fittings.

In using the flow chart (Figure 2) the designer should aim for maximum flow velocities in the range of 5–8 feet per second to minimize noise and erosion problems. For the smallest tube sizes, the designer is wise to work at the bottom of this range, as a maximum, to guard against local high velocities building up due to faulty workmanship (e.g. burrs at tube ends which are not properly reamed) or unusually numerous changes in flow direction. Locally aggressive water conditions can combine with these two considerations to cause erosion problems if velocities are too high.

The flow chart applies only to copper tube, and should not be used for other plumbing materials. Other materials require additional allowances for corrosion and caking *which are not necessary for copper.* This is because copper maintains its smooth bore throughout its service life.

Pressure ratings and burst strength

As for all materials, the allowable internal pressure for any copper tube in service is based on the formula used in the Standard Code for Pressure Piping (ANSI* B31):

$$P = \frac{2S(t_m - C)}{D - 0.8(t_m - C)}$$

where P = allowable pressure
S = allowable stress
t_m = wall thickness
D = diameter
C = a constant

For copper tube, because of copper's superior corrosion resistance, the B31 code permits the factor C to be zero. Thus the formula becomes:

$$P = \frac{2St_m}{D - 0.8t_m}$$

The value of S in the formula is an allowable design strength for continuous long-term service of the tube material. It is only a small fraction of copper's ultimate tensile strength or of the burst strength of copper tube and has been confirmed to be safe by years of service experience. The allowable stress value depends on the service temperature and on the temper of the tube, drawn or annealed.

In Table 9 the rated working pressures are shown for both annealed and drawn Types K, L, M, and DWV copper tube for service temperatures to 400°F. The ratings for drawn (hard) tube can be used only for systems using properly designed mechanical joints of the compression or flared type. Fittings manufacturers can provide information about the strength of their various types and sizes of fittings. When welding, brazing or soldering is used to join tubes, the annealed ratings are used, since the heating involved in these joining processes might anneal (soften) the hard tube. This is the reason that annealed ratings are shown in Table 9 for DWV tube, although it is not furnished in the annealed temper. Table 10 lists allowable internal working pressures for ACR tube.

In designing a system, joint ratings must also be considered,as the lower of the two ratings (tube or joint) will govern the installation. Most tubing systems are joined by soldering or brazing. Rated internal working pressures for such joints are shown in Table 11. These ratings are for Types K, L, and M tube with standard soldered pressure fittings. In soldered tubing systems, the rated strength of the joint often governs design. For brazed tubing the ratings for soft tube in Table 9 govern up to 200°F. Annealed ratings must be

*American National Standards Institute, 1430 Broadway, New York, N.Y. 10018

table 10 Rated internal working pressures (psi) for copper tube Type ACR

Size and Wall Thickness, inches	Rated Internal Working Pressure, psi						
	100F		200F		300F		400F
	Annealed	Drawn	Annealed	Drawn	Annealed	Drawn	Annealed or Drawn
1/8 (.030)	3130	—	3090	—	2620	—	1310
3/16 (.030)	1990	—	1950	—	1650	—	820
1/4 (.030)	1450	—	1420	—	1200	—	600
5/16 (.032)	1230	—	1200	—	1020	—	510
3/8 (.030)	900	1350	880	1300	740	1180	370
3/8 (.032)	1010	—	990	—	840	—	420
1/2 (.032)	740	—	730	—	610	—	300
1/2 (.035)	800	1200	780	1150	660	1060	330
5/8 (.035)	640	—	630	—	530	—	260
5/8 (.040)	740	1110	720	1060	610	980	300
3/4 (.042)	650	980	630	930	530	850	260
7/8 (.045)	590	890	570	840	480	770	240
1 1/8 (.050)	510	770	490	720	420	670	210
1 3/8 (.055)	460	690	440	650	370	590	180
1 5/8 (.060)	430	650	410	600	350	560	170
2 1/8 (.070)	370	560	360	530	300	480	150
2 5/8 (.080)	350	530	340	500	280	450	140
3 1/8 (.090)	330	500	320	470	270	430	130
3 5/8 (.100)	320	480	300	440	260	420	130
4 1/8 (.110)	300	450	290	430	240	380	120

NOTE: Based on S values as follows: 100F—6,000 psi, annealed; 9,000 psi, drawn; 200F—5,900 psi; annealed, 8,700 psi drawn; 300F—5,000 psi, annealed, 8,000 psi, drawn; 400F—2,500 psi, annealed or drawn, according to American National Standard Code for Pressure Piping, Refrigeration Piping, ANSI B31.5.

table 11 Rated internal working pressures (psi) for copper tube joints

Alloy Used for Joints	Service Temperature, °F	Environment					
		Water and Non-Corrosive Liquids and Gases					Saturated Steam
		Tube Size, Types K, L and M (in inches)					
		1/4 to 1 Incl.	1 1/4 to 2 Incl.	2 1/2 to 4 Incl.	5 to 8 Incl.	10 to 12 Incl.	All
50–50 Tin-Lead Solder[a]	100	200	175	150	130	100	—
	150	150	125	100	90	70	—
	200	100	90	75	70	50	—
	250	85	75	50	45	40	15
95–5 Tin-Antimony Solder[a]	100	500	400	300	270	150	—
	150	400	350	275	250	150	—
	200	300	250	200	180	140	—
	250	200	175	150	135	110	15
Brazing Alloys (Melting at or above 1000 F)	100–150–200	(b)	(b)	(b)	(b)	(b)	—
	250	300	210	170	150	150	—
	350	270	190	150	150	150	120

NOTE: Ratings up to 8 inches are those given in ANSI Standard B16.22 *"Wrought Copper and Bronze Solder-Joint Pressure Fittings"* and ANSI B16.18 *"Cast Bronze Solder-Joint Pressure Fittings."*

(a) Solder alloys are covered by ASTM Standard Specification B32.
(b) Rated internal pressure is that of tube being joined; see Tables 9 and 10.

table 12 Rated pressures vs. burst pressures
Type M tube at room temperature

Tube Size, inches	Tube Temper	Rated Pressure, psi			Measured Burst Pressure*, psi
		Annealed Tube	Drawn Tube	50–50 Solder	
½	Drawn	430	760	200	5900
¾	Drawn	350	610	200	4750
1	Drawn	295	515	200	4150

*Tube had soldered end closures.

used in brazed systems for hard temper tube, since brazing softens (anneals) the tube near the joints. Above 200 F, the joint ratings shown in Table 11 should govern the design of brazed systems.

The pressures at which copper tube will actually burst are many times the rated working pressures. For example, in Table 12 the rated working pressures are compared with actual burst pressures measured in tests on three sizes of Type M drawn tube. The very conservative working pressure ratings give added assurance that pressurized systems will operate successfully for long periods of time. The much higher burst pressures measured in tests indicate that tubes are well able to support pressure surges and other unpredictable loads that may occur during the long service life of the system.

Similar conservative principles were applied in arriving at the working pressures for brazed and soldered joints. The allowable stresses for the soldered joints assure joint integrity under full rated load for extended periods of time. Short-time strength and burst pressures for soldered joints are many times higher. In addition, safety factors were incorporated in calculating the joint strengths.

Drainage plumbing systems

The design and installation of drainage systems range from simple to complex, depending on the type of building, the local code, and the occupancy requirements. The local plumbing code will include requirements for acceptable materials, installation and inspection, and these must be followed as the first requirement of an acceptable job.

There are usually differences—sometimes minor, sometimes quite important—among plumbing codes. Among the features which differ from code to code may be minimum tube sizes, permissible connected fixture loads, fittings and connections, methods of venting, supports and testing. Few codes are completely specific as to installation details and leave the responsibility of proper and suitable installation to the designer and the contractor.

In large and multi-story buildings, the design will generally require the services of a mechanical engineer and plumbing designer. The plumbing designer has the responsibility for coordinating the drainage system design within the overall building construction requirements. A good drainage design must take into account the problems of installation space, building movement, support, expansion and contraction, pipe sleeves, offsets, and provisions for necessary maintenance.

In residential buildings and small one and two-story commercial buildings, the drainage piping is usually simple in design and straightforward in installation. Type DWV copper tube, installed with good workmanship by an experienced plumber, will provide long years of trouble-free service.

Because DWV tube is furnished in 20-foot lengths (which one man can easily handle) few joints are necessary in drainage stacks, branches and vents. This simplifies assembly and cuts installation costs. In an average residence the entire stack from the basement building drain through the roof — often including the water closet runouts — can be cut from a single 20-foot length of DWV. Scrap is practically eliminated.

The smaller diameter of DWV tube and fittings makes it possible to install copper drainage systems where competitive piping materials would be impossible, difficult, or more costly to install. For example, a three-inch copper stack is only 3⅜-inch outside diameter at the fitting and can be easily installed in a "2-by-4-inch" stud partition.

Prefabrication—Considerable savings can be effected by prefabricating copper DWV subassemblies. Prefabrication permits work even when adverse weather prohibits activity on the job site. Simple, inexpensive jigs can be made to position the tube and fittings during assembly and help eliminate costly dimensional errors. Freedom of movement at the bench permits joints to be made more readily than at the point of installation, where working space may be limited.

Soldered joints are strong and rigid. Subassemblies can be handled without fear of damage. The lightweight features of copper DWV tube and fittings make it possible to handle fairly large assemblies without strain. Other dependable drainage plumbing materials weigh 3 to 4 times as much, as seen in this comparison of 20-foot lengths:

Size	Weight, pounds		
	Copper DWV	Service Weight Cast Iron	Steel Pipe
1¼	15	—	45
1½	16	—	54
2	21	80	73
3	34	120	151
4	58	160	216

Subassemblies require a minimum of support when connected to previously installed sections of the drainage systems.

Copper DWV has been used successfully for years in all parts of drainage plumbing systems for high-rise buildings — the soil stacks, the vent stacks and in the soil, waste and vent branches. Copper tube's light weight and the ease with which it can be prefabricated have been especially important in high-rise drainage systems.

Expansion of DWV Systems—In high-rise buildings, expansion and contraction of the stack should be considered in the design. Possible movement of a copper tube stack as the temperature of the stack changes is approximately 0.001 inch per degree F per floor. (See Fig. 6, page 22.) This is slightly more than for iron and steel pipe and considerably less than for plastic.

Since length, temperature changes and piping design itself are all involved in expansion, the designer must determine the best way to take

figure 3 Technique for anchoring a copper DWV stack to concrete floors

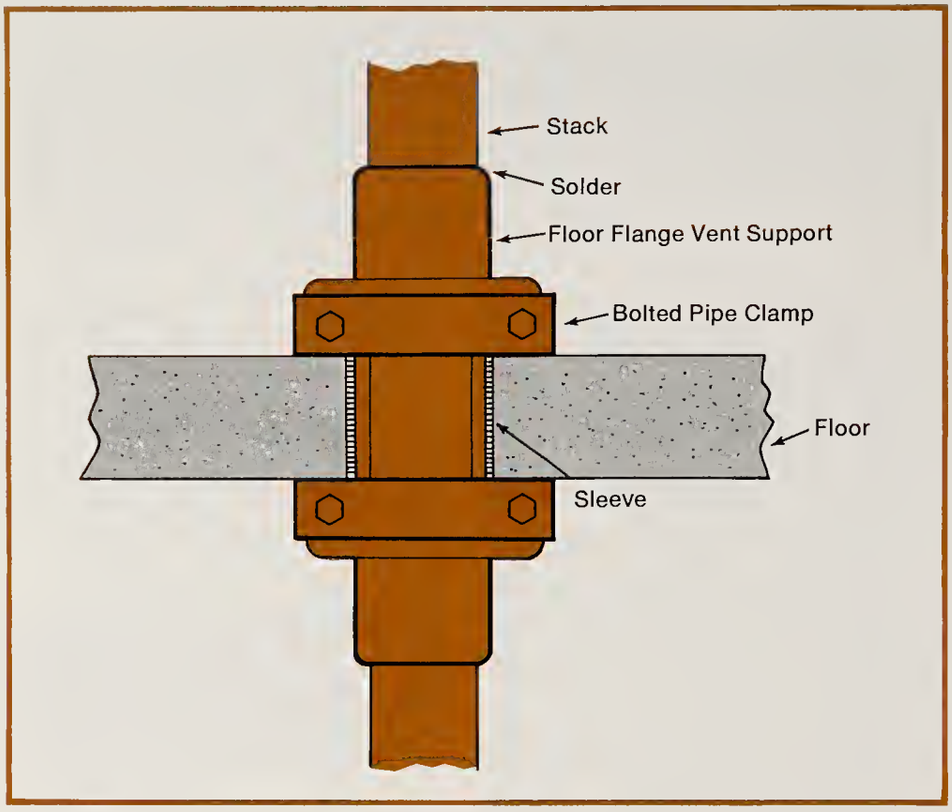


table 13 Pressure ratings for copper DWV tube joints

Maximum Service Temperature, F	Tube Size, inches	Pressure Rating, psi
Joints Made with 50–50 Tin-Lead Solder[a]		
100	1¼ to 2	95
	3 to 4	80
	5 to 8	70
150	1¼ to 2	70
	1¼ to 2	55
	5 to 8	45
200	1¼ to 2	50
	3 to 4	40
	5 to 8	35
Joints Made with 95–5 Tin-Antimony Solder[a]		
100	1¼ to 2	220
	3 to 4	165
	5 to 8	120
150	1¼ to 2	195
	3 to 4	150
	5 to 8	100
200	1¼ to 2	140
	3 to 4	110
	5 to 8	80

(a) Solder alloys are covered by ASTM B32. Pressure ratings are calculated using the same factors of safety employed for pressure fittings (Table 11) and the strengths of solders as reported in National Bureau of Standards Report BMS 58 "Strength of Soft-Soldered Joints in Copper Tubing."

care of expansion in any particular installation. One simple procedure for controlling thermal movement is to anchor the stack. Anchoring at every eighth floor will take care of an anticipated maximum temperature rise of 50F; anchoring every four floors will take care of a 100F maximum temperature rise. Perhaps the simplest effective anchor, when the stack passes through concrete floors, is to use pipe clamps and soldered fittings as shown in Figure 3. The pipe clamps can be placed above and below the floor, backed up by sliding the fittings tight against the clamps and soldering them in place. At all floors between anchors, sleeves in the concrete floors should be used to prevent lateral movement of the tube.

Allowance for Hydrostatic Testing DWV Systems — While a copper drainage system is not ordinarily operated under pressure conditions, it must withstand considerable pressure when the system is subjected to a hydrostatic test. The allowable pressures for copper DWV tube with soldered joints and standard DWV fittings are given in Table 13.

To determine the vertical height that can be statically pressure tested (with water) in one segment, take the applicable figure from Table 13 and multiply by 2.3. For example, if 50-50 solder is used and the largest tube size is 4-inch, multiply 80 (from Table 13) by 2.3; the result is 184. Thus a 184-foot vertical segment of stack could be tested at once. If 95-5 tin-antimony solder is the joining material, or if the joints are brazed, the corresponding rating for 4-inch tube from the table, 165, is multiplied by 2.3, equalling 380. Thus, theoretically, 380 feet (38 ten-foot stories) could be tested at once. The actual number tested is usually much less, and depends on practical considerations on the job.

The Single-Stack Sovent™ System

The copper Sovent single-stack plumbing system, introduced in the United States in 1968, is widely recognized as the most progressive innovation in plumbing in several decades. Copper Sovent is an engineered drainage system developed

™ O.H.C. Messner

to improve and simplify soil, waste and vent plumbing in multi-story buildings.

Since its introduction, hundreds of Sovent systems have been designed for high-rise buildings in the U.S.A. Major U.S. installations include retirement and military housing, luxury apartments, urban development high-rise complexes, motels, hotels, nursing homes and office buildings. Operating experience with these buildings shows that Sovent does have a number of advantages over conventional drainage systems. These include simplified piping, flexibility of fixture layouts, reduced structural loads, increased rental area, and overall savings in installed cost.

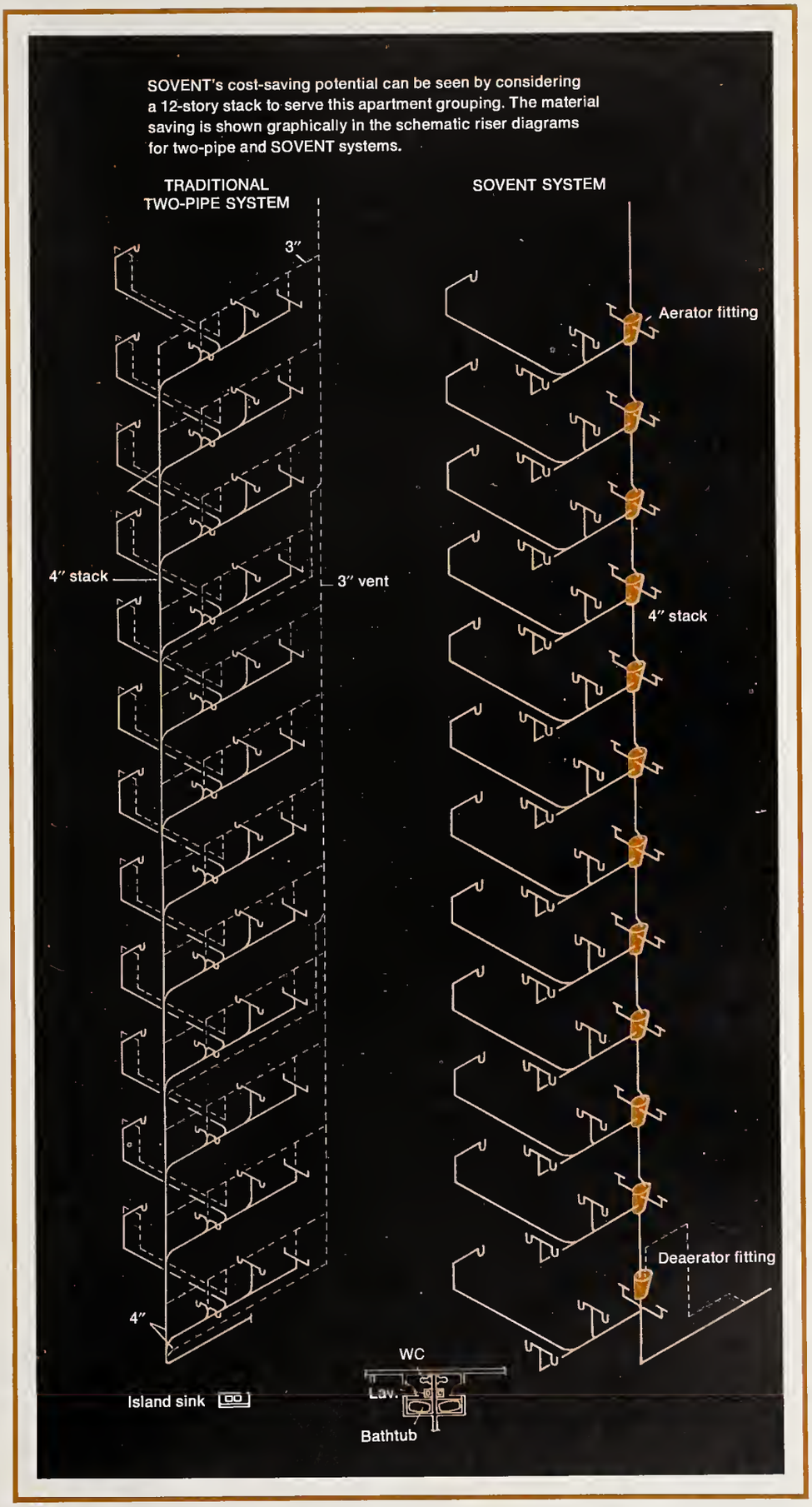
Sovent makes separate vent stacks and individual fixture vent piping obsolete, as shown in Figure 4, markedly simplifying piping arrangements. Structural impairment of wall and floor systems is minimized. There is no need to cut or drill framing members in order to accommodate vent lines. With fewer stacks, the number of floor sleeves and the size of chases is reduced. More flexible use of wall space and between-floor space accrues. In addition, simplified layouts facilitate the placement of utilities and duct work. For the first time, the drainage system can be tailored to the building without compromise and architects benefit from this new design freedom.

Sovent eliminates almost half of the material required for comparable two pipe systems. This, coupled with the use of copper tube throughout, simplifies hanger and support requirements. Dead loads imposed by the drainage system on the building's structural framing are significantly reduced.

The copper Sovent system has four parts: a copper DWV stack, a Sovent aerator fitting at each floor level, copper DWV horizontal branches, and a Sovent deaerator fitting at the base of the stack as shown in Figure 5.

The aerator does three things: (1) it limits the velocity of both liquid and air in the stack, (2) it prevents the cross section of the stack from filling with a plug of water and (3) it efficiently mixes the waste flowing in the branches with the air in the stack. The deaerator fitting separates the air flow in the stack from the liquid, ensuring smooth entry

figure 4 Comparison of the traditional two-pipe drainage system with the Single-Stack all-copper Sovent system



into the building drain and relieving the positive pressure at the bottom of the stack. The result, a single stack that is self-venting, with balanced positive and negative pressures at or near the zero line throughout the system. *SO*il stack and *VENT* are combined into a single SOVENT stack.

Each individual Sovent system must be designed to meet the conditions under which it will operate, and engineering judgment is required in applying the simple basic design concepts as enumerated in the Copper Development Association* publication, "Copper Sovent Single-Stack Plumbing System Design Handbook," a companion publication to this Copper Tube Handbook.

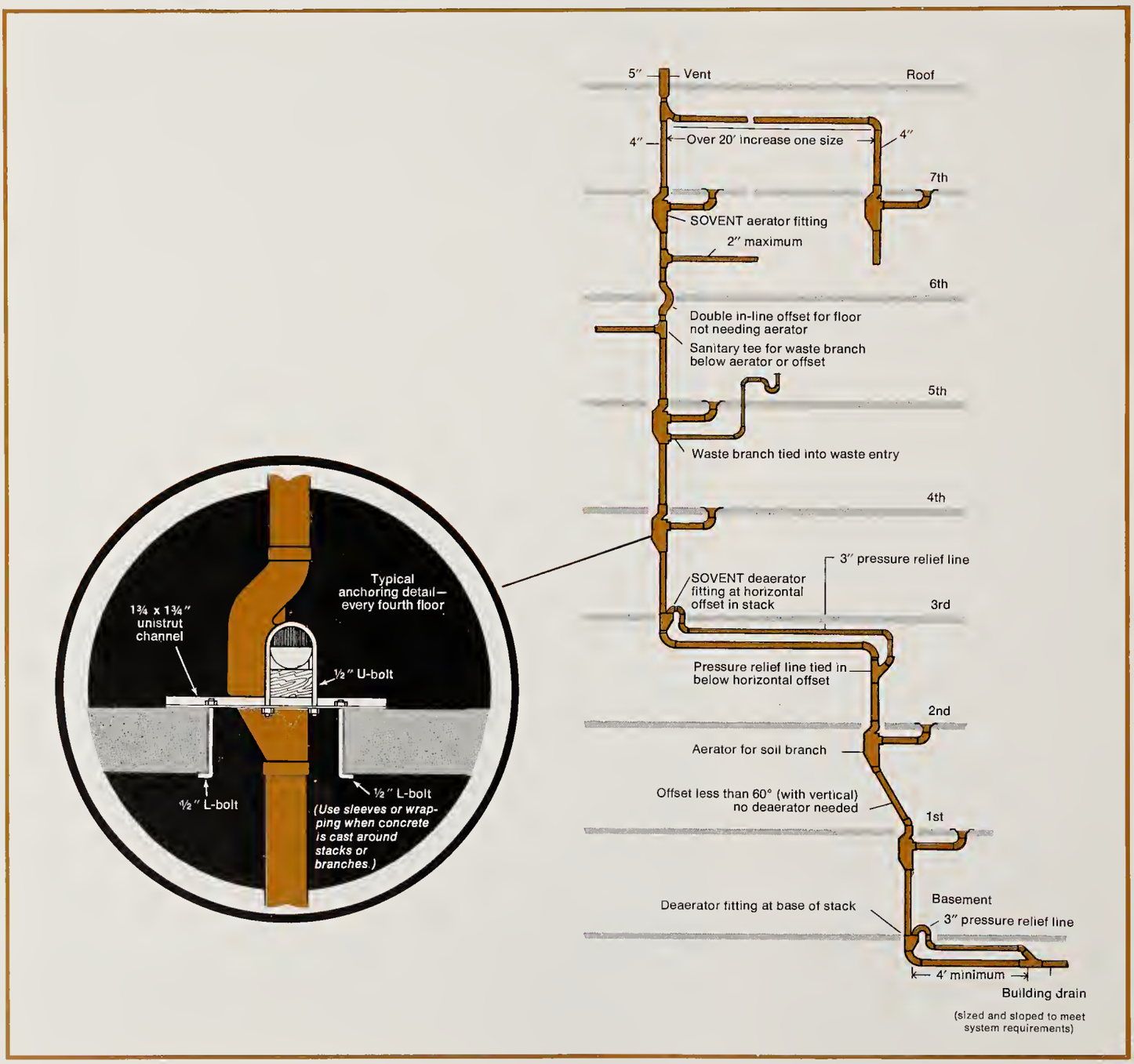
Copper tube for heating

Copper tube is popular for heating systems in both new and remodeled buildings. Contractors have learned through experience that copper tube is, all factors considered, still superior to any substitute material. The advantages of light weight, choice of tempers, long-term reliability, and ease of joining, bending and handling, are of major importance. For example, where rigidity and appearance are factors, drawn tube is recommended. Annealed tube is particularly suitable for panel heating, snow melting, and short runs to radiators, convectors, and the like. With either annealed or bending-temper tube fittings are reduced to a minimum, to give substantial savings in installation labor and material.

Forced circulation hot water heating systems provide uniform heating and quick response to changes in heating load, require little maintenance, and can be easily zoned to provide different temperature levels

*Copper Development Association Inc.
405 Lexington Avenue, New York, N.Y. 10017

figure 5 Copper Sovent drainage stack design features



throughout the building. These systems use the smallest and most economical tube sizes with soldered joints and require little space for the installation. Also, in combination with the heating system and where permitted by code, domestic hot water can be heated directly—eliminating the need for a separate water heater.

Design and installation data for heating systems are given in the *Heating and Air Conditioning Guide,* published by the American Society for Heating, Refrigeration and Air Conditioning Engineers,* as well as in literature published by manufacturers of boilers and heating specialties, and those publications should be consulted for detailed design.

Steam-Heating Return Lines — For steam-heating systems, especially return lines, the outstanding corrosion resistance and non-rusting characteristics of copper tube assure trouble-free service and maintenance of traps, valves, and other devices. On condensate and hot water return lines, it is recommended that the *last two feet before* the heating medium should be *double* the size of the rest of the line. For example, if the return line is 1-inch tube, enlarge it to 2-inch.

Radiant Panel Heating — A modern application of an ancient principle, radiant panel heating, can be used successfully in nearly all types of structures. In panel systems, low-temperature hot water, circulating through coils of copper tube embedded in a concrete floor or plaster ceiling, warms the surfaces and the air. Panel systems offer uniform heating and comfort, an invisible heat source, complete use of the floor area, cleanliness and the elimination of dust-carrying drafts.

Copper tube is the ideal piping material for floor and ceiling panels because of its lightweight, long lengths, corrosion resistance, and ease of bending, joining, and handling. Soft temper tube in coils is commonly used for sinuous heating layouts since it is easily bent and joints are reduced to a minimum. Hard temper tube is used for mains, risers, heaters, and grid-type heating coils.

Location of the heating panel is relatively unimportant for the comfort of room occupants, but it does depend on the architectural and thermal characteristics of the room. Floor installations have the advantage of low initial cost and are particularly suitable for garages, schools and churches. They are generally designed to operate at a maximum surface temperature of 85F. Above this temperature, occupants become uncomfortable. Ceiling panels, more frequently used in residences, can be operated at higher surface temperatures and heat outputs than floor panels. They respond quickly to changes in heating load, have low thermal storage, and require only a simple control system.

The tube sizes of heating coils chiefly affect the hydraulics of the heating system (see section on Pressure Systems, page 9) and are relatively unimportant from the standpoint of heat output of the panel. For sinuous floor coils ⅜-inch, ½-inch, and ¾-inch, soft temper tube is generally used with a 9-inch or 12-inch center-to-center spacing. For ceiling panel installations the sinuous coils are formed of ⅜-inch soft temper tube with a tube spacing of 4 inches or 6 inches. Soldered joints are commonly used.

*American Society for Heating, Refrig. and Air Cond. Eng., 345 E. 47th St., New York, N.Y. 10017

Oxygen Systems

Safety codes for oxygen lines and other medical gases require the use of Type L copper tube. Special cleanliness requirements are called for because oxygen under pressure may cause the spontaneous combustion of some organic oils. Copper tube for oxygen lines is furnished by the manufacturers suitably cleaned and capped or plugged. Care must be taken to prevent contamination of the system when the caps or plugs are removed and the tube is installed. The installer must satisfy himself and the inspection department that the cleanliness requirements of the code have been met. The following recommendations of NFPA publication No. 56F, *Nonflammable Medical Gas Systems* will be helpful:

CHAPTER 5. INSTALLATION AND TESTING OF PIPING SYSTEMS

51. *General*

511. Before erection, all piping, valves and fittings — except those supplied especially prepared for oxygen service by the manufacturer and received sealed on the job—shall be thoroughly cleaned of oil, grease and other readily oxidizable materials by washing in a hot solution of sodium carbonate or trisodium phosphate (proportion of one pound to three gallons of water). THE USE OF ORGANIC SOLVENTS; FOR EXAMPLE, CARBON TETRACHLORIDE, IS PROHIBITED. Scrubbing shall be employed where necessary to insure complete cleaning. After washing, the material shall be rinsed thoroughly in clean, hot water. After cleaning, particular care shall be exercised in the storage and handling of all pipe and fittings. Pipe and fittings shall be temporarily capped or plugged to prevent recontamination before final assembly. Tools used in cutting or reaming shall be kept free from oil or grease. Where such contamination has occurred, the items affected shall be rewashed and rinsed.

512. All joints in the piping, except those permitted to be approved brass flared-type gas tubing fittings and those at valves or at equipment requiring screw connections, shall be made with silver brazing alloy or similar high melting point (at least 1000F) brazing metal. Particular care shall be exercised in applying the flux to avoid leaving any excess inside the completed joints. The outside of the tube and fittings shall be cleaned by washing with hot water after assembly.

513. Screw joints used in shutoff valves, including station outlet valves, shall be installed by tinning the male thread with soft solder. Litharge and glycerin or an approved oxygen luting or sealing compound are acceptable.

514. After installation of the piping, but before installation of the outlet valves, the line should be blown clear by means of oil free dry air or nitrogen.

Snow-melting systems

Snow-melting coils, installed in walks, driveways, loading platforms, and other paved areas, are an efficient, economical means of snow, sleet, and ice removal. To warm the surface, a 50-50 solution of water and antifreeze (ethylene glycol type) is circulated through copper tube embedded in the concrete or blacktop. Considerable savings can be effected on industrial plant installations where waste heat sources can be utilized.

In general, the installation of snow melting coils is similar to that of floor panel heating coils. Selection of a sinuous or a grid pattern for a snow melting system depends largely on the shape, size, and installation conditions. Grids are good for square and rectangular areas; sinuous coils are usually preferred for irregular areas. The lower pressure loss with grid coils permits the use of smaller diameter tubes providing savings in material costs. Maximum economy is often realized with a combination of sinuous and grid-type coils.

Soft temper copper tube is suitable for both sinuous and grid-type coils; hard temper is best for larger grid coils and for mains. Soft coils facilitate the installation of sinuous coils because of the long lengths

and the ease of bending which reduce joints to a minimum.

For copper tube spaced on 12-inch centers in concrete (or on 9-inch centers in blacktop) 140 feet of ½-inch tube or 280 feet of ¾-inch tube will give a heating effect for snow melting of 100 BTU per hr per sq ft. For a heat input of 200 BTU per hr per sq ft of snow area, the maximum length for ½-inch tube is 60 feet, and for ¾-inch tube 150 feet. Solution temperature entering the coils should be 120 to 130F.

Tube in concrete should be located about 1¼ to 1½ inches below the surface. The concrete should be reinforced with wire mesh. In blacktop, 1½ inches minimum of compacted thickness of blacktop should cover the tube. The tube should be laid, with care, on compacted gravel, crushed stone or a concrete base.

The same types of heaters and circulating pumps available for radiant heating installations are suitable for snow-melting panels. The panels also may be hooked up to building comfort heating systems, if the system has sufficient capacity for the additional load and satisfactory precautions against freezing can be made.

Irrigation and Sprinkling systems

Irrigation systems are necessities in arid agricultural areas and sprinkling systems for maintaining landscaped areas are being used increasingly. Regardless of the type or size of the system, thousands of successful installations testify that copper tube is the ideal material for the lines.

With the aid of pressure loss and velocity relationships shown in Figure 2, and the instructions contained in the literature of pump and sprinkler manufacturers, plumbers can lay out a copper tube watering system to service lawns, crops or golf courses.

System lines should be laid deep enough to avoid mechanical damage by tools and they should be pitched to drain freely. Where freezing can be expected, the system should be installed below the frost line.

Expansion and contraction should not be a problem if lines are not rigidly anchored.

Solar Energy Systems

The onset of the energy crises in the mid-seventies provided a new economic impetus and an irrevocable national commitment to the use of solar energy for heating. Solar energy systems to heat domestic water and for space heating are based on adding a collector to the heating system to capture energy from the sunshine. In general, this simply involves extending the heating/plumbing system to the roof of the house, where a flat-plate solar collector is incorporated into it.

CDA publishes a Design Handbook for solar energy systems which includes an easy-to-use method for properly sizing a solar heating system to achieve the desired solar contributions to that system. For a copy of the handbook, please write: Copper Development Association Inc., 405 Lexington Avenue, New York, NY 10174.

Copper is the logical material for solar energy systems because:

(1) it has the best thermal conductivity of all engineering metals,

(2) it is highly resistant to both atmospheric and aqueous corrosion,

(3) it is easy to fabricate and to join by soldering or brazing.

(4) it has been used both for plumbing and for roofs since metals were first employed in those applications.

Copper's thermal advantages mean thinner copper sheet can collect the same heat as much thicker-gage sheet of aluminum or steel, and copper collector tubes can be more widely spaced.

Copper's resistance to atmospheric corrosion is well demonstrated by service in roofing and flashing. Over decades of time — even centuries — there has been no significant wastage of the metal by corrosion, in the absence of local corrodants.

Copper resists hot water corrosion equally well. Properly sized to keep flow rates below about 5 ft per sec, and properly installed, copper hot water systems are, for all practical purposes, completely resistant to corrosion.

The ease with which copper plumbing systems are joined by soldering needs no special emphasis. Sheet copper fabrication is equally recognized for its ease and simplicity.

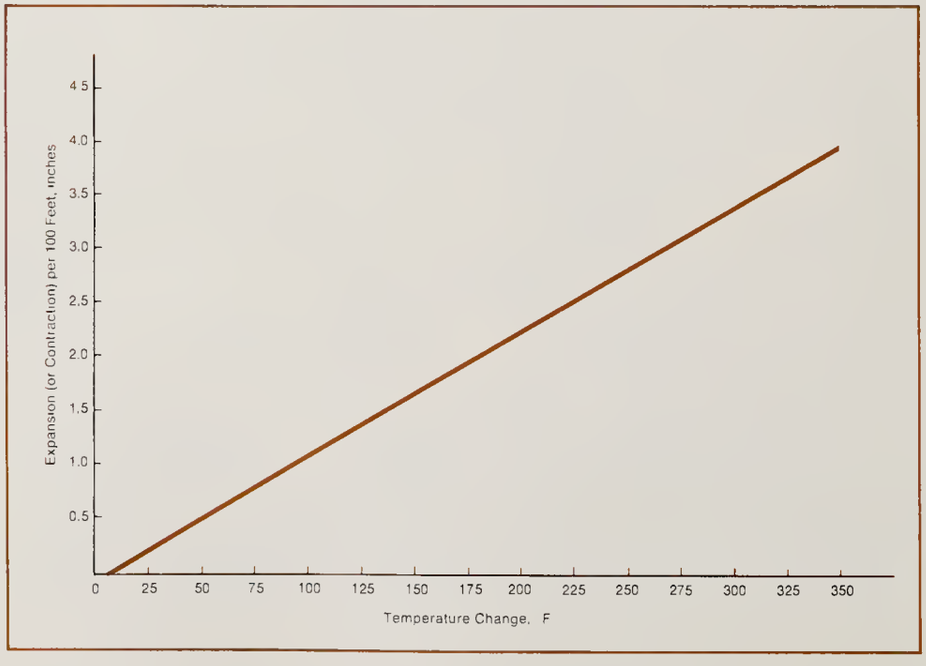
Over sixty manufacturers now supply such panels in the U.S.A. (A list describing their products is available from CDA.)

General considerations

It is not possible in a handbook of this type to cover all the variables a plumbing system designer may have to consider. However, in addition to the foregoing discussion, the following information may also prove helpful when preparing job specifications.

Expansion Loops — Copper tube, like all piping materials, expands and contracts with temperature changes. Therefore, in a copper tube system subjected to excessive temperature changes, the line tends to buckle or bend when it expands unless compensation is built into the system. Severe stresses on the joints may also occur. Such stresses, buckles, or bends are prevented by the use of expansion joints or by in-

figure 6 Expansion (per 100 feet) vs. temperature change for copper tube



stalling offsets, "U" bends, coil loops, or similar arrangements in the tube assembly. These specially shaped tube segments take up expansion and contraction without excessive stress. The expansion of a length of copper tube may be calculated from the formula:

Temperature Rise (F) × Length (feet) × 12 (inches per foot) × Expansion Coefficient (in. per in. per F) = Expansion (inches)

Calculations for expansion and contraction should be based on the average coefficient of expansion of copper which is 0.0000094 per degree F, between 70F and 212F. For example, the expansion of each 100 feet of length of any size tube heated from room temperature (70F) to 170F (a 100F rise) is 1.128 inches.

$$100^\circ \times 100 \text{ ft} \times 12 \text{ in./ft} \times 0.0000094 \text{ in./in./F} = 1.128 \text{ in.}$$

Figure 6 shows the change in length, per 100 feet of copper tube, with temperature. The expansion calculated above can also be determined by entering Figure 6 at 100F, moving up to the line, and reading across to 1.128 inches.

Table 14 gives the radius necessary for coiled expansion loops, described in Figure 7; expansion offset lengths may be estimated from Table 15. (Both on p. 24).

Alternatively, the necessary length of tube in an expansion loop or offset can be calculated utilizing the formula:

$$L = \frac{1}{12}\left(\frac{3E}{p}\right)^{1/2}(d_o e)^{1/2}$$

Where L = developed length, in feet, in the expansion loop or offset as shown in Figure 7.

E = modulus of elasticity of copper, in psi.

p = design allowable fiber stress of material in flexure, in psi.

d_o = outside diameter of pipe, in inches.

e = amount of expansion to be absorbed, in inches.

For annealed copper tube:

E = 15,600,000 psi

p = 6,000 psi, thus

The developed length L is simply:

$$L = 7.4(d_o e)^{1/2}$$

Tube Supports — Drawn tube, because of its rigidity, is preferred for exposed piping. Where not otherwise stated in plumbing codes, drawn temper tube requires support for horizontal lines at about 8-foot intervals for sizes of 1-inch and smaller, and at about 10-foot intervals for larger sizes. Vertical lines are usually supported at every story or at about 10-foot intervals, but for long lines where there are the usual provisions for expansion and contraction, anchors may be several stories apart provided there are sleeves or similar devices at all intermediate floors to restrain lateral movement.

Annealed temper tube in coils permits long runs without intermediate joints. Vertical lines of annealed temper tube should be supported at least every 10 feet. Horizontal lines should be supported at least every 8 feet.

Resistance to Crushing—Tests made by placing a ¾-inch round steel bar at right angles across a 1-inch annealed copper tube and then exerting pressure downward revealed that, even with this severe point-contact loading, 700 pounds were required to crush the tube to 75 percent of its original diameter at any temperature. Two-inch sizes, because of their greater wall thicknesses, resisted even more weight before crushing.

Plumbing codes and good piping practice require that all excavations shall be completely backfilled as soon after inspection as practical. Trenches should first be backfilled with 12 inches of tamped, clean earth which should not contain stones, cinders, or other materials which would damage the piping or cause corrosion. Mechanical devices such as bulldozers and graders may be used to complete backfilling. Suitable precautions should be taken to insure permanent stability for pipe laid in filled or made ground.

Freezing—Annealed temper tube can withstand the expansion of freezing water several times before bursting. Under test, ½-inch soft tube filled with water has been frozen as many as six times, and the 2-inch size eleven times. This is a vital safety factor favoring soft tube for underground water services. However, it does not mean that copper water tube lines should be subjected to periodic freezing.

table 14 Radii of coiled expansion loops

For configurations shown in figures 7A and 7B (page 24)

Expected Expansion, inches	Radius "R" for Tube Sizes Shown, inches												
	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5
½	6	7	8	9	11	12	13	15	16	18	19	20	23
1	9	10	11	13	15	17	18	21	23	25	27	29	32
1½	11	12	14	16	18	20	22	25	28	30	33	35	39
2	12	14	16	19	21	23	25	29	32	35	38	41	45
2½	14	16	18	21	24	26	29	33	36	40	43	45	51
3	15	17	19	23	26	29	31	36	40	43	47	50	55
3½	16	19	21	25	28	31	34	39	43	47	50	54	60
4	17	20	22	26	30	33	36	41	46	50	54	57	64

Corrosion — Copper water tube is corrosion resistant. It is very infrequent that waters or special conditions are encountered which can be corrosive to copper tube. When they are encountered, they should be recognized and dealt with.

In the past 30 years in the United States over 10 billion pounds of copper plumbing tube have been produced, 80% of which has been installed in domestic plumbing systems. This translates into over 3.5 million miles of copper plumbing since World War II. The rare problems of corrosion by aggressive water, possibly aggravated by faulty design or inadequate workmanship, should be viewed in that overall context of this total record of outstanding service performance. In general, widespread use of copper plumbing tube in a locality can be taken as good evidence that the water there is not aggressive to copper.

The rarely-encountered corrosion problems are of five main types: (1) aggressive, hard well waters that cause pitting; (2) soft, acidic waters that do not allow a protective film to form inside the copper tube; (3) system design or installation which results in excessive water flow velocity or turbulence in the tube; (4) lapses in good workmanship, and (5) aggressive soil conditions.

Aggressive pitting waters can be identified by chemical analysis and treated to bring their composition within acceptable limits. Characteristically they have high total dissolved solids (t.d.s.) including sulfates and chlorides, a pH in the range of 7.3 to 7.8, a high content of carbon dioxide (CO_2) gas (over 10 parts per million, ppm), and the presence of dissolved oxygen (D.O.) gas. A qualified water treatment engineer can specify a treatment for any aggressive well water to make it non-aggressive to plumbing materials. In general, this involves raising the pH and combining or eliminating the CO_2 gas. Sometimes simple aeration of the water, e.g. spraying in the open air, is treatment enough.

Pitting can also be caused or intensified by faulty workmanship which leaves excessive amounts of residual aggressive flux inside the tube after installation. If the joints have been overheated during installation and the excess residual flux has polymerized, the pitting problem can worsen.

Soft acidic waters can cause the annoying problem of green staining of fixtures or "green water." Raising the pH of such waters to a value of about 7 or more usually solves the problem, but a qualified water treatment engineer should be consulted. A typical treatment is to flow the water through a bed of marble chips.

Excessive water velocity causes erosion-corrosion or impingement attack in plumbing tube and piping systems. As explained in the discussion of pressure system sizing beginning on page 9, to avoid erosion-corrosion (and noise) problems, flow in a plumbing system should not exceed 5 to 8 feet per second maximum — the lower limit applying for the smaller tube sizes in the system. Velocity effects can be aggravated if the water is also chemically aggressive due to pH or gas content as outlined above, or if solids (silt) are entrained in the flow. The combination of a flow rate that is otherwise acceptable and a water chemistry that is on the threshold of being aggressive can cause trouble that would not result from either contributing factor by itself.

Erosion-corrosion can also be aggravated by faulty workmanship. For example, if burrs are left behind at cut tube ends they can upset the streamlined flow and cause turbulence and localized very high velocities, resulting in corrosion.

Any metal pipe laid in cinders is subject to attack by the acid generated when sulfur compounds in the cinders combine with water. Under such circumstances, the tube should be isolated from the cinders with an inert moisture barrier, a wrapping of insulating tape, a coating of an asphaltum paint, or with some other approved material. Most natural soils do not attack copper.

Copper drainage tube rarely corrodes except when misused, or when errors have been made in designing or installing the drainage system.* Improper horizontal slope can permit corrosive solutions to lie in the tube and attack it. If hydrogen sulfide gas is allowed to vent back into the house drainage system, it can attack the tube.

*"Service Experience with Copper Plumbing Tube," MATERIALS PROTECTION AND PERFORMANCE, 11 (2), pp. 48-53 (February, 1972), National Association of Corrosion Engineers.

figure 7 Expansion loops and offsets

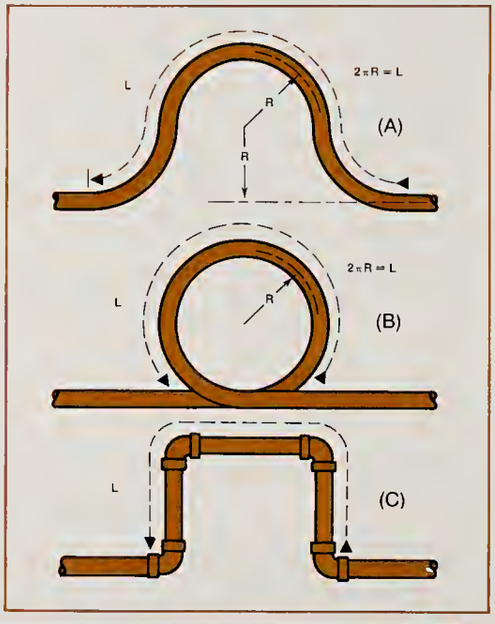
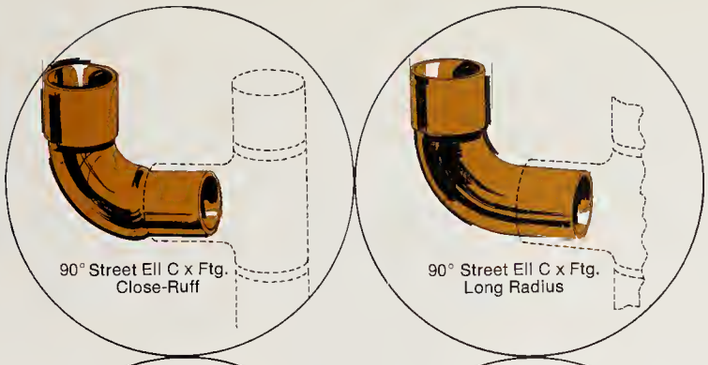
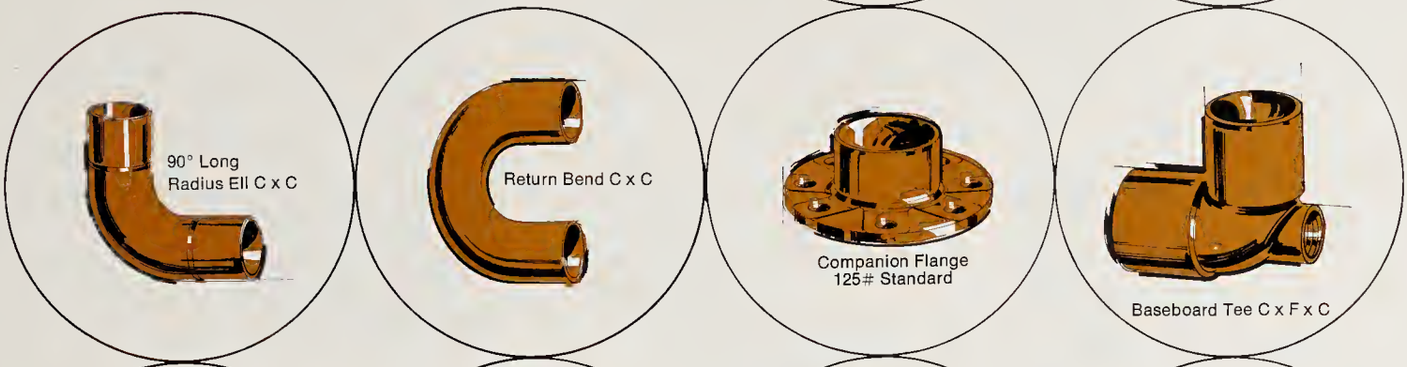


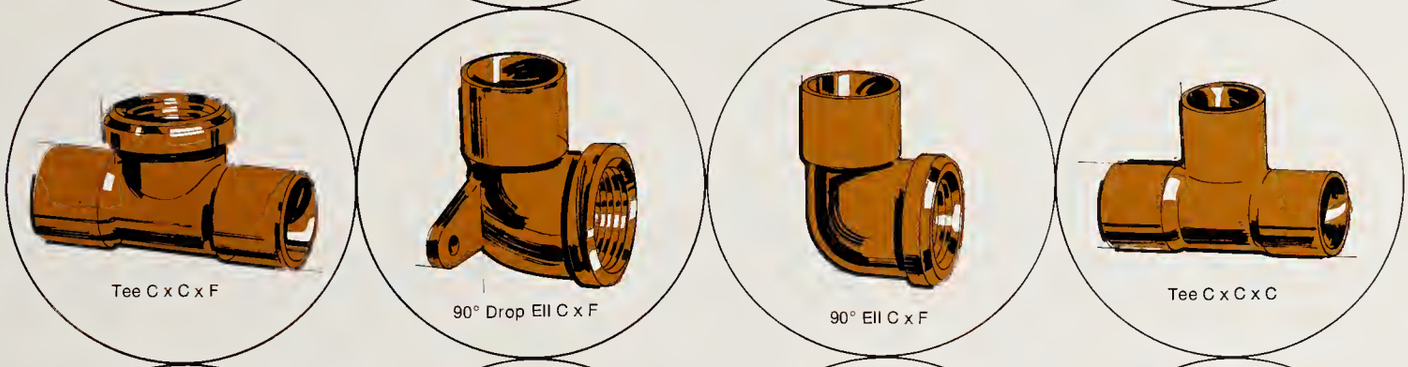
table 15 Developed length of expansion offsets
For configuration shown in Figure 7C (right)

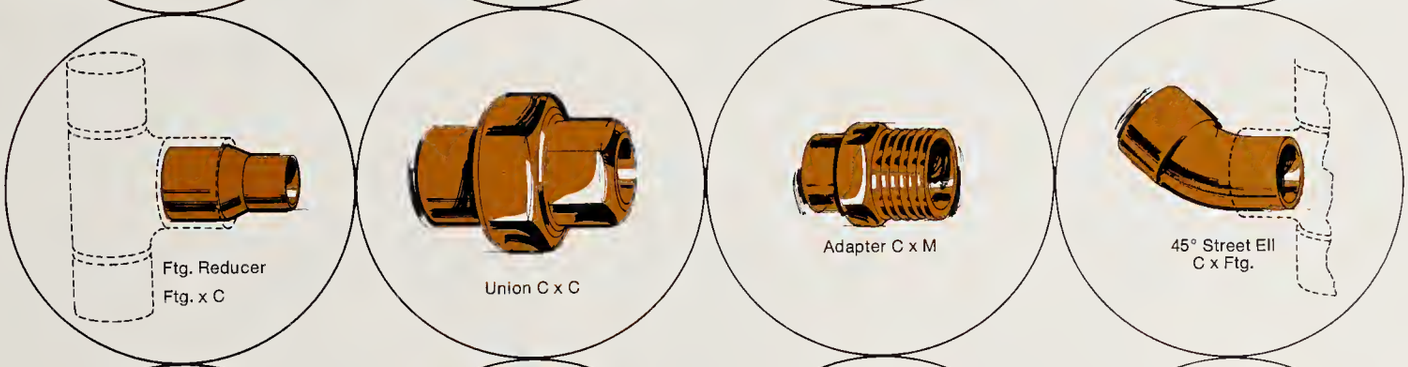
Expected Expansion, inches	Length "L" for Tube Sizes Shown, inches												
	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5
½	38	44	50	59	67	74	80	91	102	111	120	128	142
1	54	63	70	83	94	104	113	129	144	157	169	180	201
1½	66	77	86	101	115	127	138	158	176	191	206	220	245
2	77	89	99	117	133	147	160	183	203	222	239	255	284
2½	86	99	111	131	149	165	179	205	227	248	267	285	318
3	94	109	122	143	163	180	196	224	249	272	293	312	348
3½	102	117	131	155	176	195	212	242	269	293	316	337	376
4	109	126	140	166	188	208	226	259	288	314	338	361	402

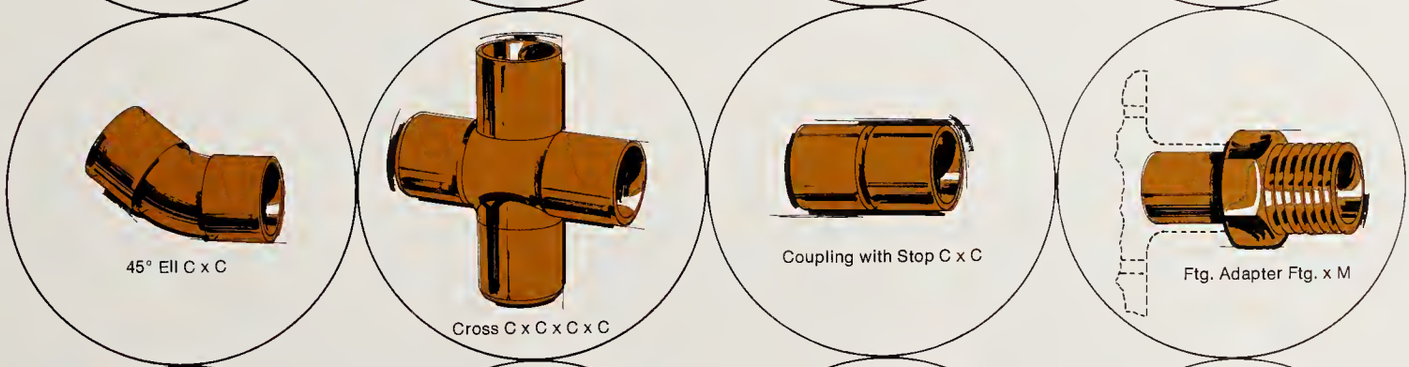
figure 8 Typical pressure fittings

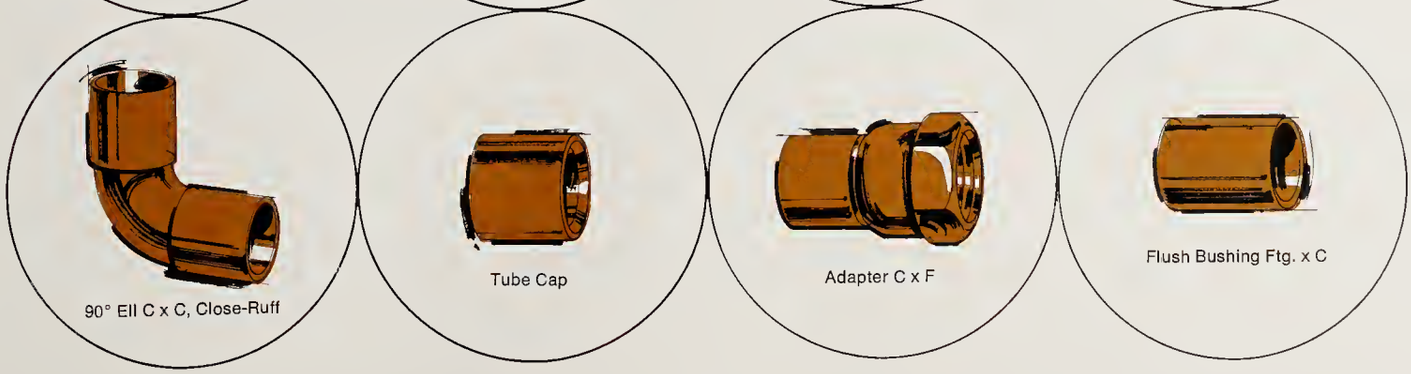












Vibration—Copper tube installations can withstand vibration caused by heavy traffic, pump pulsations, etc. The use of copper tube in motor vehicles, aircraft, warships and commercial vessels has demonstrated conclusively the ability of copper tubing to withstand the effects of vibration when careful consideration is given to the design. Care should be taken when installing systems subject to vibration to assure that they are free from residual stresses due to bending or forced fit-up. Residual stresses, coupled with vibration, can cause fatigue at bends and connections where such residual stresses have been built into the system.

Durability—Under normal conditions, a correctly designed and properly installed copper water tube assembly will easily last the life of the building. And, throughout its existence, it should function as well as it did when originally installed.

Water Hammer — Water hammer is the term used to describe the destructive forces, pounding noises and vibrations which develop in a water system when the flowing liquid is stopped abruptly by a closing valve.

When water hammer occurs, a high-pressure shock wave reverberates within the piping system until the energy has been spent in frictional losses. The noise of such excessive pressure surges such as this may be prevented by adding a capped air chamber or surge arresting device to the system.

Arresting devices are available commercially to provide permanent protection against shock from water hammer. They are designed so the water in the system will not contact the air cushion in the arrester and, once installed, they require no further maintenance.

On single-fixture branch lines, the arrester should be placed immediately upstream from the fixture valve. On multiple-fixture branch lines, the preferred location for the arrester is on the branch line supplying the fixture group between the last two fixture supply pipes.

Joining and bending

The most common method of joining copper tube is by soldering with capillary fittings. Soldered joints are used in plumbing for water lines, and for sanitary drainage. Brazed joints, with capillary fittings, are used where greater strength is required or where service temperatures are as high as 350F. Brazing is preferred, and often required, for joints in refrigeration piping. Mechanical joints are used frequently for underground tubing, for joints where the use of heat is impractical and for joints that may have to be disconnected from time to time. Copper tube may also be joined by butt-welding without the use of fittings.

Fittings

Fittings for copper water tube used in plumbing and heating are made to the following standards: *Cast Bronze Threaded Fittings,* (ANSI B16.15); *Cast Bronze Solder Joint Pressure Fittings,* (ANSI B16.18); *Wrought Copper and Bronze Solder Joint Pressure Fittings,* (ANSI B16.22); *Cast Copper Alloy Solder Joint Drainage Fittings DWV,* (ANSI B16.23); *Bronze Flanges and Flanged Fittings,* (ANSI B16.24); *Cast Copper Alloy Fittings for Flared Copper Tubes,* (ANSI B16.26); *Wrought Copper and Wrought Copper-Alloy Solder Joint Drainage Fittings,* (ANSI B16.29); *Non-ferrous Pipe Flanges,* (ANSI B16.31), and *Cast Bronze Solder Joint Fittings for SOVENT Drainage Fittings,* (ANSI B16.32).

*American National Standards Institute, 1430 Broadway, New York, N.Y. 10018

Examples of fittings are shown in Figures 8 (pg. 25), 9 and 10.

Cast bronze pressure fittings are available in all standard tube sizes and in a wide variety of types to cover needs for plumbing and heating. They can be either soldered or brazed, although brazing cast fittings requires care. Wrought copper pressure fittings are also available over a wide range of sizes and types. These, too, can be joined by either soldering or brazing and wrought fittings are preferred where brazing is the joining method. Otherwise, the choice between cast and wrought fittings is largely a matter of the user's preference.

Flared-tube fittings provide metal-to-metal contact similar to ground joint unions; both can be easily taken apart and reassembled. They are especially useful where residual water cannot be removed from the tube and soldering is difficult. Flared joints may be required where a fire hazard exists and the use of a torch to make soldered or brazed joints is not allowed. Also, soldering under wet conditions can be very difficult and flared joints are preferred under such circumstances.

Solders

Soldered joints depend on capillary action drawing free-flowing molten solder into the gap between the fitting and the tube. Flux, applied first, acts as a cleaning and wetting agent and, when properly applied, permits uniform spreading of the molten solder over the surfaces to be soldered. Capillary action is most effective when the space between the surfaces to be joined is between 0.002 inch and 0.005 inch (.004 inch to .010 inch diametral clearance).

The selection of a solder depends on the operating pressure and temperature of the line. Consideration should also be given to the stresses on the joint caused by thermal expansion and contraction. However, stresses due to temperature changes should not be significant in two commonly encountered cases: when tube lengths are short, or when expansion loops are used in long tube runs (page 24).

Rated internal working pressures for solder-fitting joints made with copper tube using 50-50 tin-lead solder and 95-5 tin-antimony solder are listed in Table 11 (page 16). The 50-50 tin-lead solder is suitable for moderate pressures and temperatures. For higher pressures, or where greater joint strength is required, 95-5 tin-antimony solder can be used. For continuous operation at temperatures exceeding 250F, or where the highest joint strength is required, brazing filler metals should be used.

Solder of composition 40% tin and 60% lead has been used for plumbing applications with a reasonable degree of success. However, it is somewhat less easy to use than the more popular 50-50 solder. The 95-5 tin-antimony solder is more difficult to use as it melts at a slightly higher temperature than does the 50-50 solder and has a very narrow solidification range.

figure 9 Typical drainage fittings

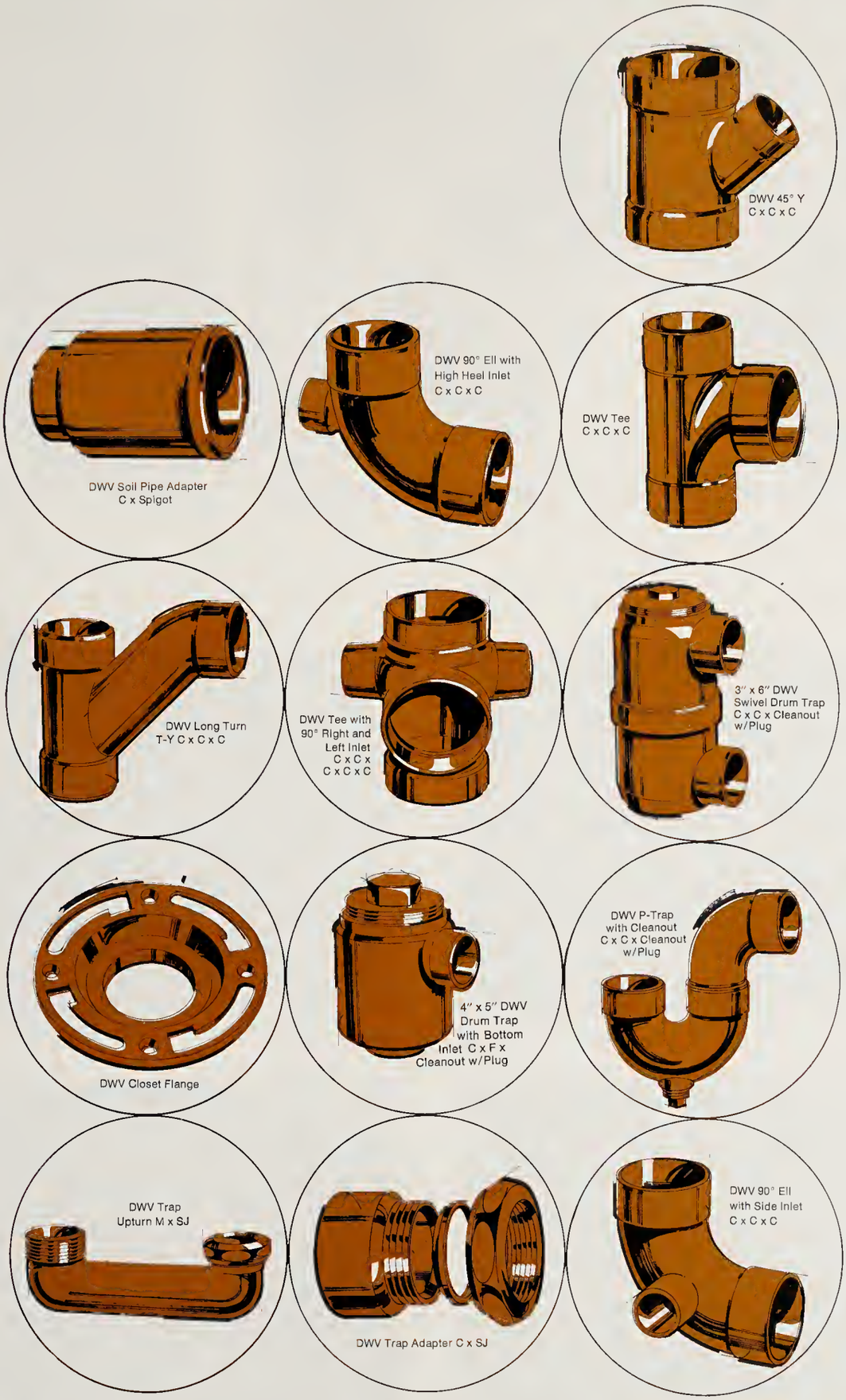
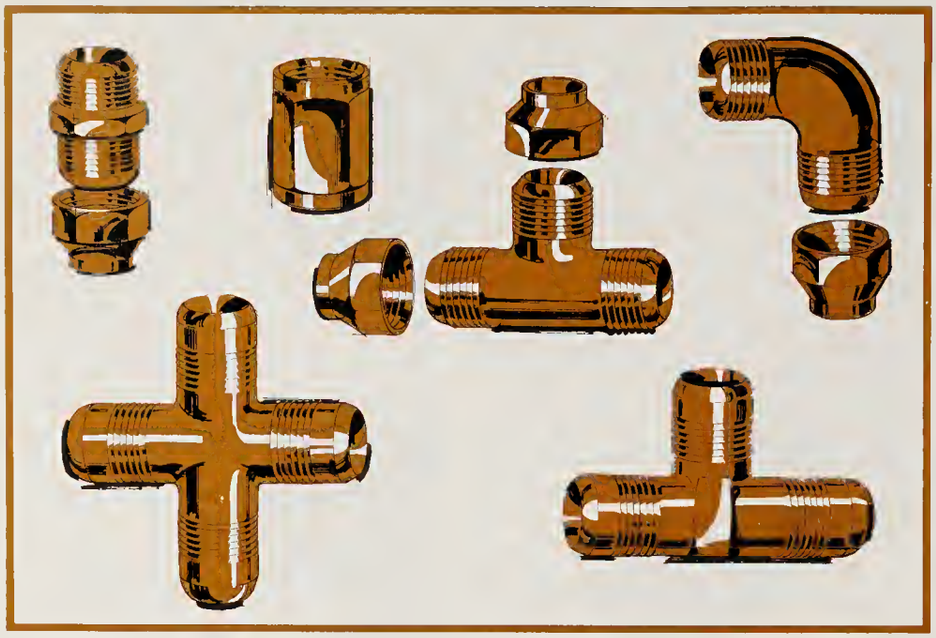


figure 10 Typical flared-tube fittings (See page 37)



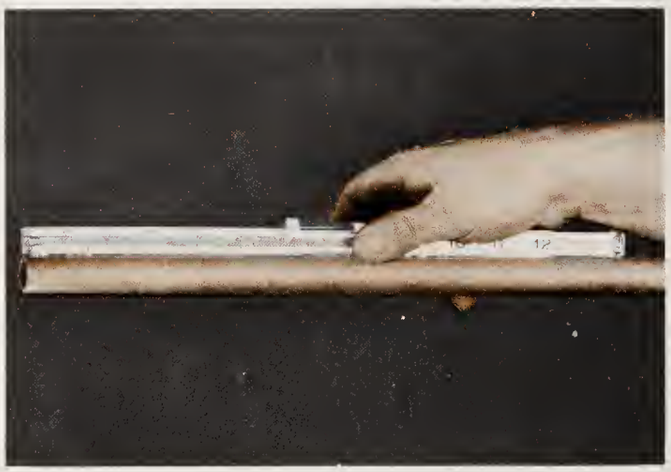
Solder is generally used in wire form, but paste-type solders are also available. These are finely granulated solders in suspension in a paste flux. When using paste-type solders observe these four rules:

1. Wire solder must be applied *in addition to the paste* to fill the voids and assist in displacing the flux, otherwise the surfaces may be well "tinned" and yet there may not be a good joint with a continuous bond.

2. The paste mixture must be thoroughly stirred if it has been standing in the can for more than a very short time, as the solder has a tendency to settle rapidly to the bottom.

3. The flux cannot be depended on to clean the tube. Cleaning should be done manually as is recommended for any other flux and solder.

4. Remove any excess flux.



1. Measuring

3. Reaming

2. Cutting

4. Cleaning tube end

Solders are available containing small amounts of silver or other additives to impart special properties. Such solders may require special fluxes. The manufacturer's recommendations should be consulted regarding proper procedures and fluxes for such solders and about the expected properties.

Fluxes

The functions of the soldering flux are to remove residual traces of oxides, to promote wetting and to protect the surfaces to be soldered from oxidation during heating. The flux should be applied to clean surfaces and only enough should be used to lightly coat the areas to be joined.

An oxide film may reform quickly on copper after it has been cleaned. Therefore, the flux should be applied as soon as possible after cleaning.

The fluxes best suited to the 50-50 and 95-5 solders are mildly corrosive liquid or petroleum-based pastes containing chlorides of zinc and ammonium.

Most liquid fluxes are so-called "self-cleaning" fluxes and their use involves a risk. Some paste-type fluxes are also identified by their manufacturers as "self-cleaning" and there is a similar risk in their use. There is no doubt that a strong corrosive flux can remove some oxides and dirt films. However, when highly corrosive fluxes are used this way, there is always an uncertainty as to whether or not uniform cleaning has been achieved and whether corrosive action continues after the soldering has been completed.

Soldered joints

There are twelve simple steps to make a solder joint:

1. Measure length of tube
2. Cut tube square
3. Ream cut end
4. Clean tube end
5. Clean fitting socket
6. Apply flux to tube end
7. Apply flux to fitting socket
8. Assemble
9. Remove excess flux
10. Apply heat
11. Apply solder
12. Allow joint to cool.

Although these operations are basically simple, they make the difference between good joints and poor ones. Most of these steps take less time to do than to describe. For best results none should be omitted.

Measuring—Measuring the length of tube is not really part of the soldering job, but inaccuracy can affect joint quality. If a piece of tube is too short it will not reach all the way into

5. Cleaning fitting socket

7. Fluxing fitting socket

6. Fluxing tube end

8. Assembling fitting and tube

the socket of the fitting and a proper joint cannot be made.

Cutting—Tube should be cut to exact length with a square cut. Tube cutters are generally used for sizes up to about 1 inch; large size cutters for tube up to 8 inches are available. An alternate method is to cut with a hacksaw blade or abrasive saw.

Reaming—The tube cutter will leave a small burr on the end of the tube which should be removed, using the reamer attached to the cutter or some other appropriate tool. If the tube is cut with a hacksaw, there may be both burrs and slivers, which should be removed.

If the tube is out of round, as may happen when a soft temper tube coil has been straightened, it can be brought to true dimension and roundness with a sizing tool which consists of a plug and a sizing ring.

Cleaning—Surfaces to be joined must be clean and free from oil, grease and heavy oxide. The end of the tube should be cleaned for a distance only slightly more than is required to enter the socket of the fitting. Fine sand cloth (00), cleaning pads or special wire brushes may be used. Rub hard enough to remove the surface film or soil, but not hard enough to remove metal. If the cleaning is done on work in place, care should be taken that particles of material do not fall into the tube or fitting.

The socket of the fitting should be similarly cleaned, and the same precautions observed.

Tube and fittings are made to close tolerances and abrasive cleaning should not remove a significant amount of metal. If too much metal is removed during cleaning, the capillary space may become so large that a poor joint will result.

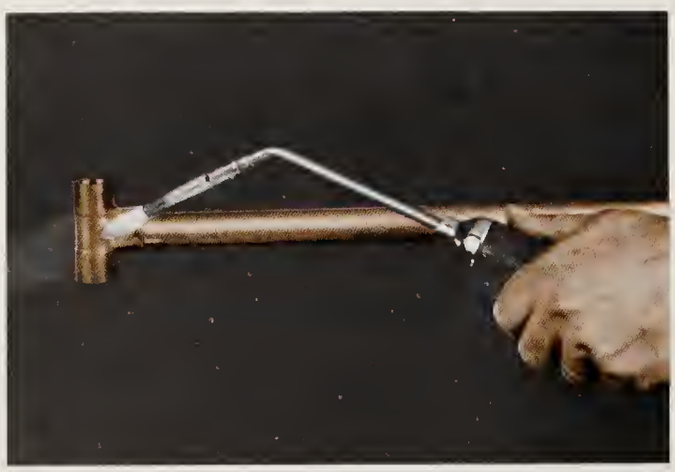
Fluxing—As soon as possible after cleaning, the surfaces to be joined should be covered with a thin film of flux. The preferred flux is one that is mildly corrosive, containing zinc and ammonium chlorides. In some paste fluxes the chemicals have a tendency to settle during long standing, so the paste should be thoroughly stirred when a new can is opened or when an opened can has been standing more than a few hours. The flux can be applied with a small brush or a clean rag. Since rags are apt to pick up dirt, they should be changed frequently.

Avoid using fingers to apply flux. Flux accidentally carried to the eyes can be very harmful.

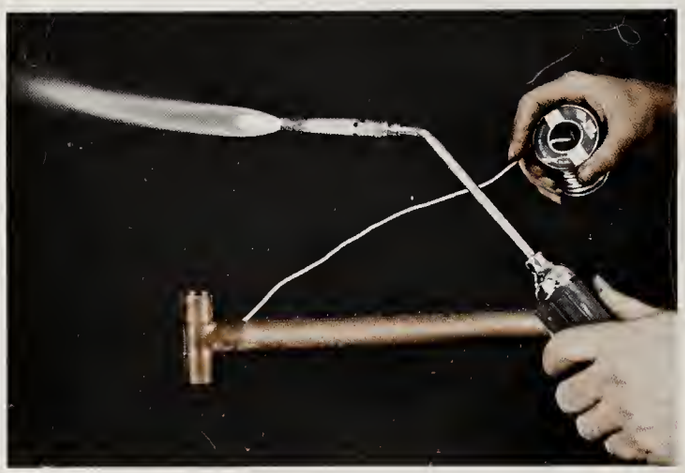
Particular care should be exercised to avoid leaving excess flux inside the completed joint. (See Corrosion section, P. 24.)

Assembling—Assemble the joint by inserting the tube into the fitting socket, making sure that the tube is firmly against the end of the socket. A small twist will help spread the flux over the two surfaces. Remove the excess flux with a rag. The joint is now ready for soldering.

9. Removing excess flux



10. Heating the assembly



11. Applying solder

12. The finished joint

It is frequently the practice to clean, flux, and assemble a series of joints before soldering. However, assembling joints more than two or three hours ahead of soldering is not recommended, and the fluxed assembly should never be left overnight before soldering.

Applying Heat and Solder — Heat is usually applied with a propane or butane torch or with an air-acetylene or an oxy-acetylene torch. The flame is played on the fitting and moved in order to heat as large an area as possible. Do not point the flame into the socket. Avoid overheating, which will burn the flux and destroy its effectiveness. If the flux has been burned, the solder will not enter the joint, and the joint must be opened, recleaned, and refluxed. Cast fittings should not be overheated because they might crack.

When the joint is hot enough, the solder will melt on contact with the tube and the flame should be moved away. If the solder does not melt, remove it, continue to heat, then try again. For large fittings, a multiple tip or ring-type torch may be useful. After the initial application of solder, complete penetration and filling of the joint can be effected by alternating application of heat and solder.

Opinions differ as to when a solder fillet is necessary or desirable. Unless specifications require fillets, they should be omitted.

If the metal is properly cleaned and fluxed, capillary action should draw all the solder needed into the joint. Pretinning is not necessary and generally is not recommended for the tube sizes used in ordinary plumbing installations. Pretinning may actually interfere to some extent with the capillary action.

Soldered joints depend on capillary action drawing free-flowing molten solder into the narrow clearance between the fitting and the tube. Flux, applied first, acts as a cleaning and wetting agent and, when properly applied, permits uniform spreading of the molten solder over the surfaces to be soldered. Capillary action is the most effective when the space between the surfaces to be joined is between 0.002 inch and 0.005 inch (.004 inch to .010 inch diametral clearance). A certain amount of looseness of fit can be tolerated, but loose fit can cause difficulties with large size fittings. This is particularly true for horizontal joints. An oversize fitting with the tube resting directly on the socket will result in too large a gap at the top. If a horizontal joint is being made and if the capillary space is maximum, the tube should be centered, and supported before soldering. Poor alignment contributes to poor joints. Wherever possible, joints should be made up in subassemblies in the vertical position, before installation.

For joining copper tube to solder-cup valves, follow the manufacturer's instructions. The valve should be in the full open position before applying heat and the heat should be applied to the tube only.

The amount of solder consumed when adequately filling the capillary space between the tube and either wrought or cast fittings may be estimated from Table 16. The flux requirement is usually 2 ounces per pound of solder.

Cooling — Allow joint to cool naturally for some time if cast fittings are used. Too rapid cooling can crack cast fittings.

When the entire assembly has been completed, test it by turning on the water. If the joints have been made as described, there should be no leaks. However, if a leak is discovered the tube must be drained, as a few drops of water may interfere with reheating the joint to repair it.

table 16 Typical consumption of 95–5, tin-antimony solder per 100 joints*

Tube Size, inches	Solder Required,* pounds	Flux Required,* ounces
¼–⅝	½	1
¾ & 1	¾	1½
1¼ & 1½	1	2
2	2	4
2½	2½	5
3	3	6
3½	3½	7
4	4	8
5	7	14
6	10	20
8	16	32

*Includes an allowance of 100% to cover wastage and loss for tube sizes up to two-inch and 25% for tube sizes 2½-inch and larger.

Brazed joints

Strong leak-tight brazed connections for copper tube may be made by brazing with filler metals which melt at temperatures in the range between 1100 and 1500F, as listed in Table 17. Brazing filler metals are sometimes referred to as "hard solders" or "silver solders"—confusing terms which should be avoided.

The temperature at which filler metal starts to melt on heating is known as the *solidus* temperature; the *liquidus* temperature is the higher temperature at which the filler metal is completely melted. The liquidus temperature is the minimum temperature at which brazing will take place. The difference between solidus and liquidus is known as the *melting range* and may be of importance when selecting a filler. It indicates the width of the working range for the alloy and the speed with which the alloy will become fully solid after brazing. Narrow ranges require more care and solidify more quickly. The melting ranges of common brazing alloys are shown in Figure 11 on page 35.

table 17 Filler metals for brazing

AWS Classification	Principal Elements, percent					
	Silver	Phosphorus	Zinc	Cadmium*	Tin	Copper
BCuP–2		7.00–7.50				Balance
BCuP–3	4.75–5.25	5.75–6.25				Balance
BCuP–4	5.75–6.25	7.00–7.50				Balance
BCuP–5	14.5–15.5	4.75–5.25				Balance
BAg–1*	44–46		14–18	23–25*		14–16
BAg–2*	34–36		19–23	17–19*		25–27
BAg–5	44–46		23–27			29–31
BAg–7	55–57		15–19		4.5–5.5	21–23

*WARNING: BAg1 and BAg2 contain cadmium. Heating when brazing can produce highly toxic fumes. Avoid breathing fumes. Use adequate ventilation.

Brazing filler metals suitable for joining copper tube are of two classes: (1) alloys containing 30 to 60% silver (the BAg series) and, (2) copper alloys which contain phosphorus (the BCuP series). See Table 17. The two classes differ in their melting, fluxing, and flowing characteristics and these should be considered in selection of a filler metal. For joining copper tube any of these filler metals will provide the necessary strength when used with standard solder-type fittings or commercially available short-cup brazing fittings.

The strength of a brazed copper tube joint does not vary much with the different filler metals, but depends mainly on maintaining the proper clearance between the outside of the tube and socket of the fitting. Copper tube and solder-type fittings are accurately made for each other and the tolerances permitted for each assure that the capillary space will be within the limits necessary for a joint of satisfactory strength. The rated internal working pressures of brazed water lines at

1. Fluxing

3. Heating small tube

2. Assembling

4. Heating small fitting

service temperatures up to 350F (the temperature for saturated steam at 120 psi) are shown in Table 11. (Page 16.) These pressure ratings should be used only when a fitting made to close tolerances has been used and the correct capillary space has been maintained.

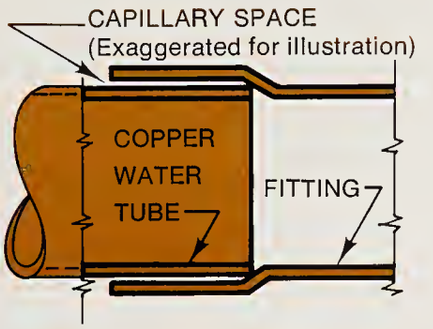
In preparing to braze a joint, the preliminary steps of tube measuring, cutting, removing burrs, and cleaning are identical to the steps in the soldering process. *Tube ends and sockets must be thoroughly cleaned before beginning the brazing operation.*

Best results will be obtained by the step-by-step brazing procedure that follows:

Fluxing—Fluxing should be done in accordance with the recommendations of the manufacturer of the brazing filler metal being used. The flux is applied with a brush to the cleaned area of the tube end and the fitting socket. If the outside of the fitting and the heat-affected area of the tube are covered with flux, it will prevent oxidation and greatly improve the appearance of the joint. Avoid getting flux inside the tube iself.

Flux may be omitted when joining copper tubes to wrought copper fittings with copper-phosphorus alloys (BCuP Series), which are self-fluxing on copper. Fluxes are required for joining to cast (bronze) fittings.

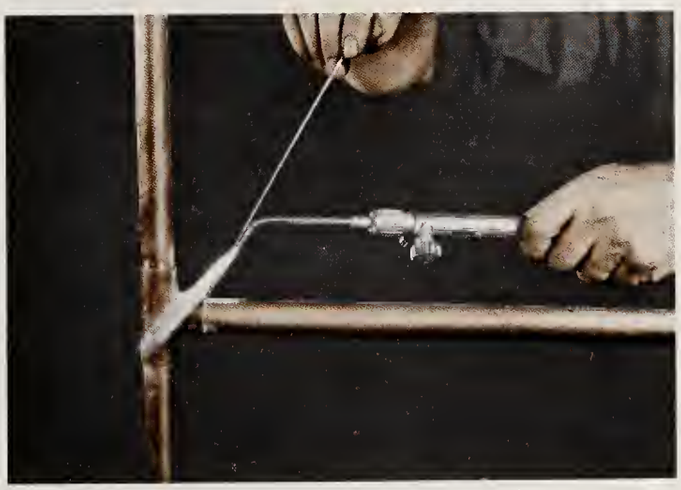
The trade names for the brazing filler metals are shown in Table 18. While any of the listed filler metals may be used, those most commonly used in plumbing, pipe fitting, refrigeration, and air-conditioning are BCuP-4 (for close tolerances), BCuP-5 (where close tolerances cannot be held) and BAg-1.



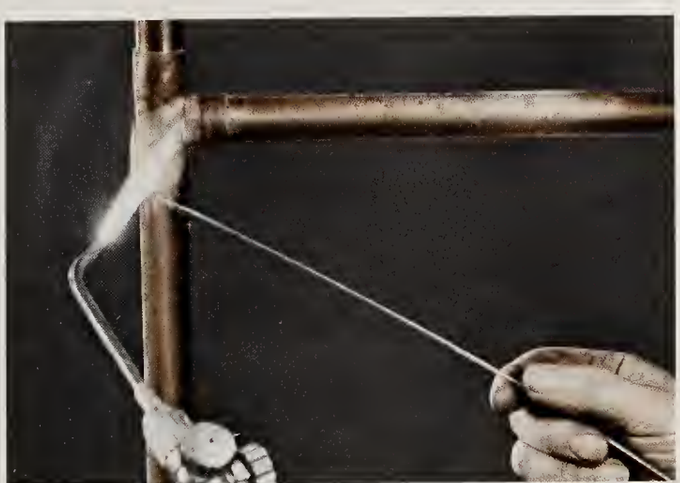
Assembling—Assemble the joint by inserting the tube into the socket hard against the stop and turn if possible. The assembly should be firmly supported so that it will remain in alignment during the brazing operation.

Applying Heat and Brazing

1. Apply heat to the parts to be joined; preferably with an oxy-acetylene flame. Air-acetylene is sometimes used on smaller sizes. A slightly reducing (excess fuel) flame should be used, with a feather on the inner blue cone; the outer portion of the flame should be white. Heat the tube first, beginning about one inch from the edge of the fitting, sweeping the flame around the tube in short strokes at right angles to the axis of the tube. It is very important that the flame be in motion continuously and not remain on any one point long enough to damage the tube. The flux may be used as a


5. Feeding brazing alloy to horizontal joint

7. Removing residue


6. Feeding brazing alloy upward in vertical joint

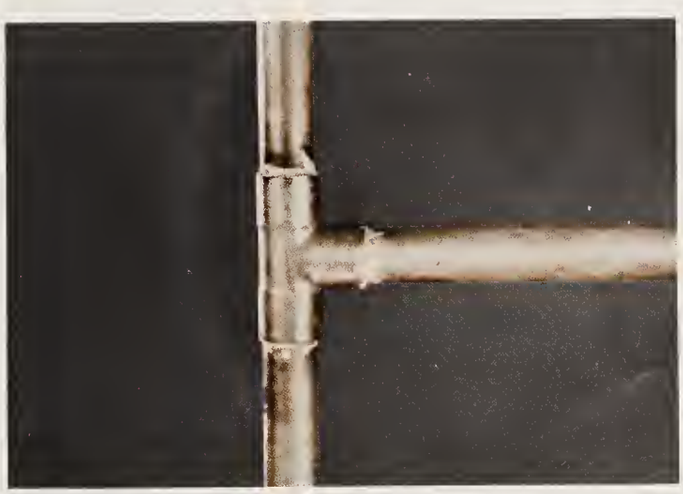

8. Completed brazed joint

table 18 Trade names for brazing filler metals

MANUFACTURER	AWS CLASSIFICATION							
	BCuP-2	BCuP-3	BCuP-4	BCuP-5	BAg1*	BAg2*	BAg5	BAg7
Air Products & Chemicals, Inc.	AP-Sil 0	AP-Sil 5	AP-Sil 6	AP-Sil 15	AP-Sil 45	AP-Sil 35	—	—
Airco Welding Products	Phos Copper Rod	Phos Silver 3M	Phos Silver 6	Aircosil 15	Aircosil 45	Aircosil 35	Aircosil G	Aircosil J
Alloy Metals, Inc.	AMDRY Phos Copper	—	—	—	—	—	—	—
Allweld Alloys, Inc.	Allweld Phos Braze # 0	Allweld Phos Braze # 5	Allweld Phos Braze # 6F	Allweld Phos Braze # 15	Allweld 45	Allweld 35	Allweld 450	Allweld 56
Aufhauser Brothers	Aufhauser BCuP-2	Aufhauser BCuP-3	Aufhauser BCuP-4	Aufhauser BCuP-5	Aufhauser BAg-1	Aufhauser BAg-2	Aufhauser BAg-5	Aufhauser BAg-7
Bowman Distribution Barnes Group, Inc.	—	—	—	—	—	—	Bowma-braze 875	Bowma-braze 877
Brite-Weld Corporation	PC-0	PC-5	PC-6	PC-15	Sil Brite 45	Sil Brite 35	—	Sil Brite 56
Chemetron Welding Products	All-State Silflo "0"	All-State Silfio "5"	—	All-State Silfio "15"	All-State No. 101	—	—	All-State No. 155
Englehard Minerals & Chemicals	Silvaloy 0	Silvaloy 5	—	Silvaloy 15	Silvaloy 45	Silvaloy 35	Silvaloy A18	Silvaloy 355
Federated Metals Corp. Newark Plant	Asarco 1300	Asarco 1220-5	Asarco 1200	Asarco 1180	Asarco 45	Asarco 35	Asarco 145	Asarco 56
Fusion, Inc.	1300	1305	1306	1315	1000	1100	1250	1205
Handy & Harman	Fos Flo 7	Sil Fos 5	Sil Fos 6	Sil Fos 7	Easy Flo 45	Easy Flo 35	Braze 450	Braze 560
J. W. Harris Co., Inc.	Stay-Silv 0	Stay-Silv 5	Stay Silv 6	Stay-Silv 15	Stay-Silv 45	Stay-Silv 35	Safety-Silv 1370	Safety-Silv 1200
International Welding Products, Inc.	Inweld 520	Inweld 521	Inweld 523	Inweld 522	Inweld 510 510FC	Inweld BAg-2	Inweld BAg-5	Inweld 511, 511FC
J D B Alloys, Inc.	Braze-It 0	Braze-It 5	Braze-It 6	Braze-It 15	Braze-It 45	Braze-It 35	Braze-It 45 Cd.Fr.	Braze-It 56
Latamer Company, Inc.	Latco 0	Latco 5	Latco 6	Latco 15	Latco 45	Latco 35	Latco BAg-5	Latco BAg-7
Liquid Air, Inc.	—	LAI S-5	—	LAI S-15	LAI S-45	LAI S-35	—	LAI S-355
Lucas-Milhaupt, Inc.	Fos Flo 7	Sil Fos 5	—	Sil Fos	Easy Flo 45	Easy Flo 35	Braze 450 (DE)	Braze 560

table 18 (cont'd)

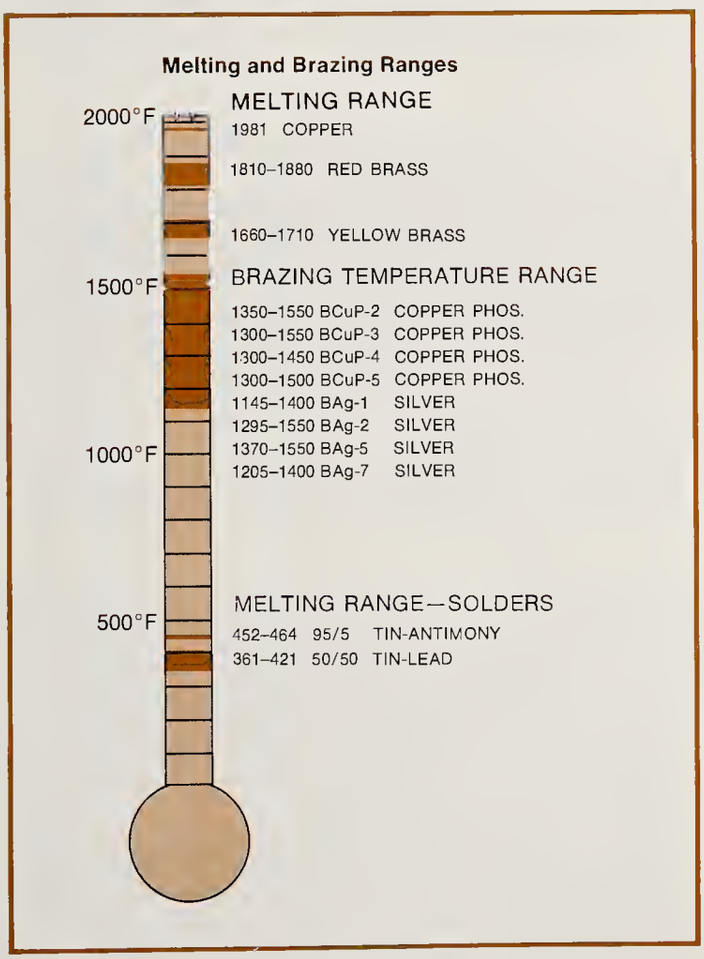
MANUFACTURER	AWS CLASSIFICATION							
	BCuP-2	BCuP-3	BCuP-4	BCuP-5	BAg1*	BAg2*	BAg5	BAg7
Marquette (Div. of Applied Power, Inc.)	—	—	—	—	No. 1175 Silver Alloy Rod	—	—	—
Nassau Research Corp.	Venus G BCuP-2	Venus G BCuP-3	Venus G BCuP-4	Venus G BCuP-5	Nassau BAg-1	Nassau BAg-2	Nassau BAg-5	Nassau BAg-7
Thermacote-Welco Co.	Welco Silv-R-Fos "0"	Welco Silv-R-Fos "5"	—	Welco Silv-R-Fos "15"	Welco 201Cd, 204FC	—	Welco 201	Welco 200 203FC
Tricon Brazing Alloys, Inc.	Fos-Flo 7	Sil Fos 5	—	Sil-Fos	EF45	EF35	BR450 (DE)	BR560
United Wire & Supply Corp.	Phoson 0	Phoson 5	—	Phoson 15 45	Sil Bond 45	Sil Bond 35	Sil 45	Sil 56T
Unibraze Corporation	Unibraze 0	Unibraze 5	Unibraze 6	Unibraze 15	Unibraze 45, 1010	Unibraze 35	Unibraze BAg-5 45CF	Unibraze 1550
Westinghouse Electric Corp.	Phos Copper	Phos Silver 5	Phos Silver 6	Phos Silver 15	Co Silver 45C	Co Silver 35C	Co Silver 45C	Co Silver 50T

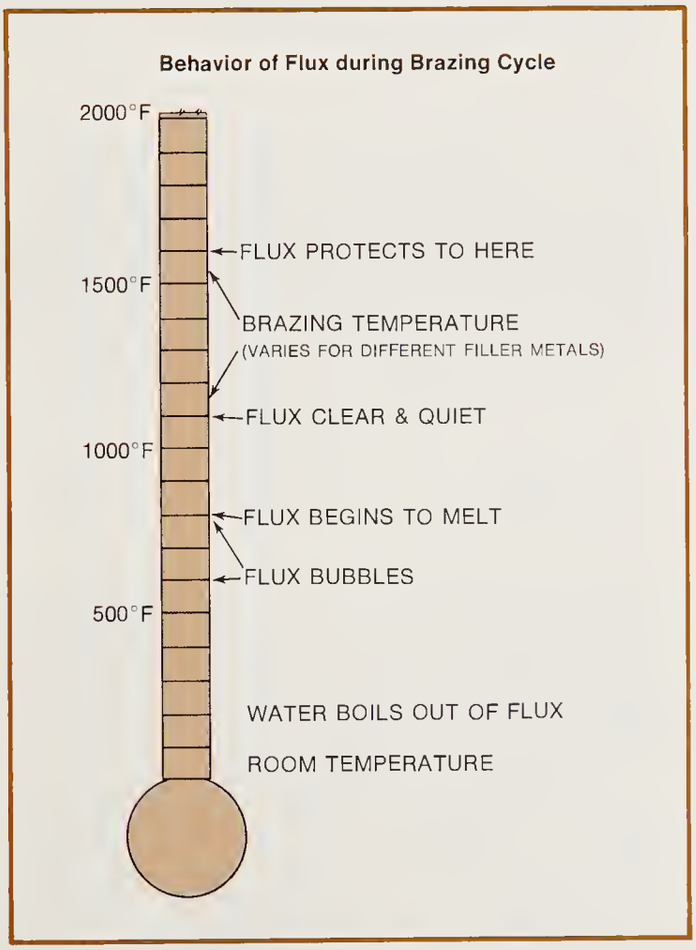
SOURCE: AWS A5, 8—76 "Filler Metal Comparison Charts," American Welding Society, Miami, Florida.

The information in this comparison chart has been obtained from the manufacturer or supplier of the particular filler metal at the time of issue. Neither the American Welding Society nor the Copper Development Association Inc. assumes responsibility for the accuracy of the listings. Filler metals are not "approved" by the American Welding Society or by the Copper Development Association Inc. The manufacturer or supplier should be consulted regarding his guarantee of compliance to specifications.

*WARNING: BAg1 and BAg2 contain cadmium. Heating when brazing can produce toxic fumes. Avoid breathing fumes. Use adequate ventilation.

figure 11 Brazing parameters





guide as to how long to heat the tube; continue heating the tube until the flux becomes quiet and transparent, like clear water. The behavior of flux during the brazing cycle is described in Figure 11.

2. Switch the flame to the fitting at the base of the cup. Heat uniformly, sweeping the flame from the fitting to the tube until the flux on the fitting becomes quiet. Avoid excessive heating of cast fittings.

3. When the flux appears liquid and transparent on both the tube and fitting, start sweeping the flame back and forth along the axis of the joint to maintain heat on the parts to be joined, especially toward the base of the cup of the fitting. The flame must be kept moving to avoid burning the tube or fitting.

4. Apply the brazing wire, rod or strip at a point where the tube enters the socket of the fitting. When the proper temperature is reached, the filler metal will flow readily into the space between the tube and the fitting socket, drawn in by the natural force of capillary attraction. Keep the flame away from the rod or wire itself as it is fed into the joint. The temperature of the joint itself should be hot enough to melt the filler metal. Keep both the fitting and tube heated by moving the flame back and forth from one to the other as the filler metal is drawn into the joint. When the joint is properly made, a continuous fillet of filler metal will be visible completely around the joint. Stop feeding as soon as you see that fillet. Table 19 is a guide for estimating how much filler metal will be consumed, along with recommended torch tip sizes and gas settings.

For 1-inch tube and larger it may be difficult to bring the whole joint up to heat at one time. It frequently will be found desirable to use a multiple tip torch to maintain the proper temperature over the large area. A mild preheating of the whole fitting is recommended for larger sizes. Heating then can proceed as outlined in the steps above. If difficulty is encountered in getting the entire joint up to the desired temperature at one time, a portion of the joint can be heated and brazed at a time, proceeding by segments progressively all around the joint.

Horizontal and Vertical Joints— When making horizontal joints it is preferable to first apply the filler metal at the bottom, then the two sides, and finally the top, making sure the operations overlap. On vertical joints it is immaterial where the start is made. If the opening of the socket is pointing down, care should be taken to avoid overheating the tube, as this may cause the brazing alloy to run down the outside of the tube. If this happens, take the heat away and allow the alloy to set. Then reheat the cup of the fitting to draw up the alloy.

Removing Residue — After the brazing alloy has solidified, clean off flux residue with a wet brush or swab. Wrought fittings may be chilled quickly; however, it is advisable to allow cast fittings to cool naturally to some extent before wetting.

General Hints and Suggestions — If the filler metal fails to flow or has a tendency to ball up, it indicates oxidation on the metal surfaces or insufficient heat on the parts to be joined. If work starts to oxidize during heating there is too little flux.

table 19 Typical brazing parameters for copper plumbing tube

Tube Size, inches	Consumption of Filler[a]			Torch Tip Drill Size No.	Acetylene Flow, cubic ft per hr	Pressure of Each Gas, lbs per sq inch
	1/16-inch Wire	3/32-inch Wire	.050 x 1/8-inch Strip			
1/4	3/4	–	–	54	15.9	4
3/8	1	–	–	54	15.9	4
1/2	1 1/2	3/4	7/8	51	24.8	5
3/4	2	1	1 1/8	51	24.8	5
1	3	1 1/2	1 5/8	48	31.6	6
1 1/4	4	2	2 1/8	48	31.6	6
1 1/2	–	2 1/2	2 5/8	44	38.7	7
2	–	3 3/4	4	40	60.0	7
2 1/2	–	6	7	40	60.0	7
3	–	10	11	35	70.0	7 1/2
3 1/2	–	12	13	35	70.0	7 1/2
4	–	14	15 1/2	30	88.5	9
5	–	16 1/2	18	30	88.5	9
6	–	21	23	30	88.5	9

(a) Approximate consumption when brazing one cup of the fitting. Actual consumption depends on workmanship. For filler sizes shown one pound of filler alloy provides 1,068 inches of 1/16-inch wire, 475 inches of 3/32-inch wire or 524 inches of .050 x 1/8-inch strip. Other filler sizes are also available.

If the filler metal does not enter the joint and tends to flow over the outside of either member of the joint, it indicates that one member is overheated or the other is underheated.

Flared joints

Impact or screw-type tools are used for flaring tube. The procedure for impact flaring is as follows:

1. Cut the tube to the required length.

2. Remove all burrs. This is very important to assure metal-to-metal contact.

3. Slip the coupling nut over the end of the tube.

4. Insert flaring tool into the tube end. (Photo 1.)

5. Drive the flaring tool by hammer strokes, expanding the end of the tube to the desired flare. *(Caution: Use eye protection.)* This requires a few moderately light strokes. (Photo 2.)

6. Assemble the joint by placing the fitting squarely against the flare. Engage the coupling nut with the fitting threads. (Photo 3.) Tighten with two wrenches, one on the nut and one on the fitting.

Using screw-type flaring tools the procedure is as follows:

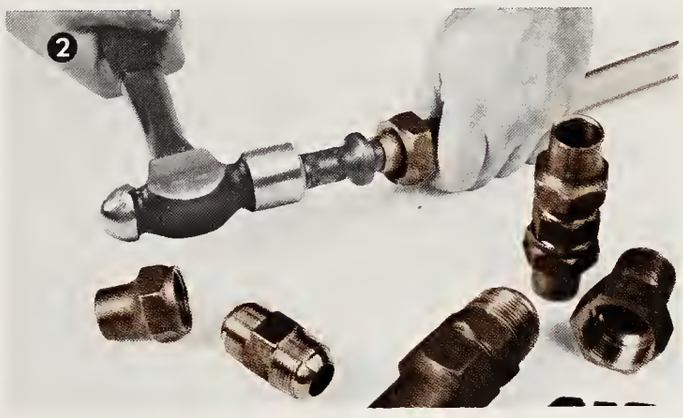
1-3. Same as for impact flaring previously described.

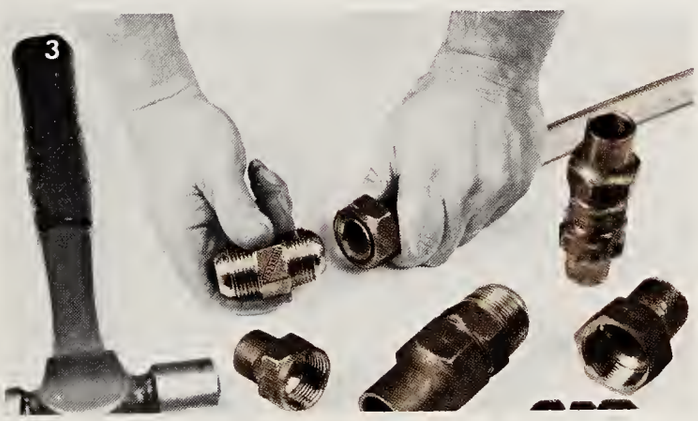
4. Clamp the tube in the flaring block so that the end of the tube is slightly above the face of the block. (Photo 4.)

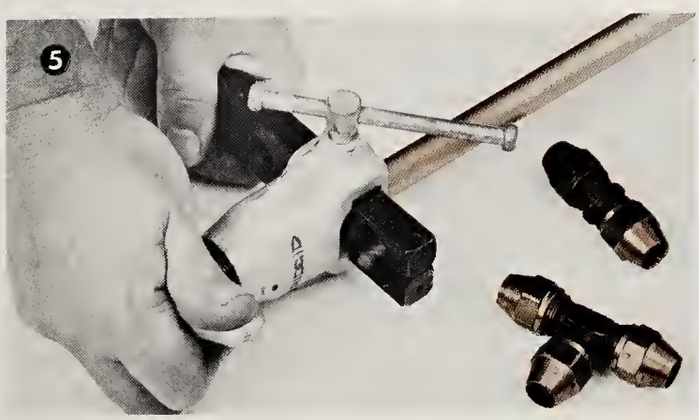
5. Place the yoke of the flaring tool on the block so that the beveled end of the compressor cone is over the tube end.

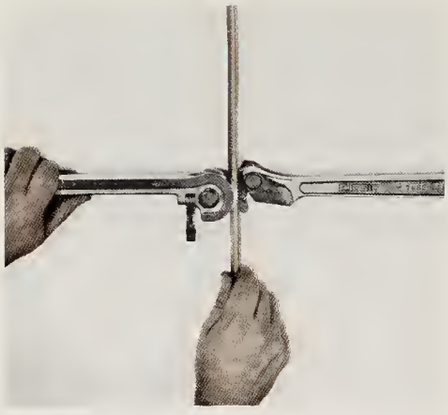
6. Turn the compressor screw down firmly, forming the flare between the chamber in the flaring block and the beveled compressor cone. (Photo 5.)

7. Remove the flaring tool. The joint can now be assembled as in step 6 for impact flaring. (Photo 6.)









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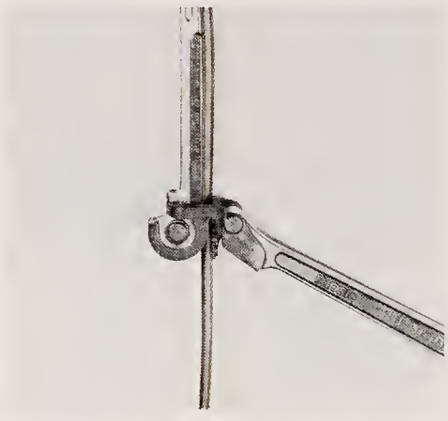

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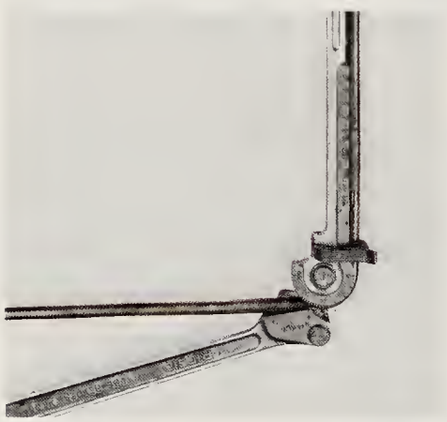

(C)

(D)

Bending

Because of its excellent formability, copper can be formed as desired at the job site. Copper tube, properly bent, will not collapse on the outside of the bend and will not buckle on the inside of the bend. Tests demonstrate that the bursting strength of a bent copper tube can be greater than it was before bending. Because copper is readily formed, expansion loops and other bends necessary in an assembly are quickly and simply made if the proper method and equipment are used. Simple hand tools employing mandrels, dies, forms, and fillers, or power-operated bending machines, are used.

Both annealed tube and bending-temper tube can be bent with hand benders. The proper size bender for each size tube must be used. Usually the size of the tool corresponds to the nominal outside diameter of the tube, not the standard tube size. For a guide to the typical bend radii, see Table 20, for both machine bending and bending by hand using circular wooden discs.

The procedure for bending copper tube with a lever-type hand bender is illustrated. (A) With the handles at 180° and the tube-holding clip raised out of the way, insert the tube in the forming-wheel groove. (B) Place the tube-holding clip over the tube and bring the handle into an approximately right angle position, engaging the forming shoe over the tube. The zero mark on the forming wheel should then be even with the front edge of the forming shoe. (C) Bend by pulling the handles toward each other in a smooth, continuous motion. The desired angle of the bend will be indicated by the calibrations on the forming wheel. (D) Remove the bent tube by pivoting the handle to a right angle with the tube, disengaging the forming shoe. Then release the tube holding the clip. Of course, if the manufacturer of the tube bender has special instructions regarding his product, such instructions should be followed.

table 20 Bending guide for copper tube

Tube Size, inches	Tube Type	Temper	Minimum Bend Radius, inches	Type of Bending Equipment
¼	K, L	Annealed	¾	Lever type
⅜	K, L	Annealed	1½	Lever or gear type
			3	None; by hand*
	K, L, M	Drawn	1¾	Gear type
½	K, L	Annealed	2¼	Lever or gear type
			4½	None; by hand*
	K, L, M	Drawn	2½	Gear type
¾	K, L	Annealed	3	Lever or gear type
	K		4½	None; by hand*
	L		6	None; by hand*
	K	Drawn	3	Gear type
	K, L		4	Heavy-duty gear type
1	K, L	Annealed	4	Gear type
			7½	None; by hand*
1¼	K, L	Annealed	9	None; by hand*

*When bending by hand, without the use of bending equipment, a circular wooden disc is used. The radius of the disc should be about ¼ to ½ inch less than the minimum bend radius shown.

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For additional technical assistance, contact:

Copper Development Association Inc.
Greenwich Office Park 2
Box 1840
Greenwich, Conn. 06836-1840
Telephone: 203/625-8210

To the user:
We hope you have found this handbook informative and useful. Please let us know how you feel it could be improved.

COPPER DEVELOPMENT ASSOCIATION INC.
405 LEXINGTON AVENUE, NEW YORK, N.Y. 10174

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MONTANA SOLAR HOT WATER

HEAT EXCHANGER SIZING FOR SDHW SYSTEMS

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

SDHW System Heat Exchanger Sizing Examples

The basic heat transfer equations used to analyze and size heat exchangers are the following:

1) $$q = V \rho C_p \Delta T$$

and

2) $$q = U_o A_o \Delta T_{LM}$$

where

q = heat transferred (Btu/hr)

V = volumetric flow rate of fluid (gal/hr)

ρ = density of fluid (lb/gal)

C_p = heat capacity of fluid (Btu/lb-^oF)

ΔT = temperature difference of the fluid entering and leaving the exchanger (^oF)

U_o = overall heat transfer coefficient (Btu/hr-ft^2-^oF)

A_o = overall area of heat exchange surface (ft^2)

ΔT_{LM} = the "log mean" average temperature difference of the fluids entering and leaving the exchanger (^oF)

We can use Equation 2 to size an exchanger (i.e. find A_o) if we know q, U_o, and ΔT_{LM} by rearranging Equation 2:

$$A_o = \frac{q}{U_o \Delta T_{LM}}$$

Heat exchanger manufacturers can be consulted for assistance in sizing SDHW system exchangers and often they can provide sizing charts, graphs, etc. to help the designer. The designer can also use guidelines and estimates for q, U_o, and ΔT_{LM}, in order to get a simplified estimate of A_o for a given SDHW system application.

When applying guidelines and estimates for q, U_o, and ΔT_{LM}, one should adopt a "conservative" approach so that the exchanger will contain a sufficent heat transfer surface area (A_o) to satisfy the needs of the SDHW system under different operating conditions (various levels of solar radiation, temperature, flow rates, fluid type, etc.) A conservative approach to heat exchanger sizing means that we should select the highest anticipated value for q and the lowest anticipated values for U_o and ΔT_{LM} in order to find A_o.

Following are the guidelines for q, U_o and ΔT_{LM} recommended for simplified sizing of SDHW system heat exchangers. The guidelines were developed from heat exchangers. The guidelines were developed from heat exchanger manufacturer's data and sizing methods.

q - Range 50-200 $\frac{\text{Btu delivered by solar collectors}}{\text{hr-ft}^2 \text{ of collector area}}$

U_o - Range 100-400 $\frac{\text{Btu transferred}}{\text{hr-ft}^2 \text{ of exchanger} - {}^{o}\text{F}}$

(For external, forced circulation, counter-flow heat exchangers)

U_o - Range 20-120 $\frac{\text{Btu transferred}}{\text{hr-ft}^2 \text{ of exchanger} - {}^{o}\text{F}}$

(For internal coil-in-tank, integral tank wall, and thermosiphon heat exchangers

ΔT_{LM} - Range 10-25 ^{o}F

Now we can use these guidelines to estimate the size (A_o) of common SDHW system heat exchangers. It is important that the designer/installer follows the heat exchanger manufacturer's recommendations for piping, flow rates, fluid type, etc. when making the final selection of an exchanger and when installing the exchanger.

EXAMPLE 1

Estimate the heat exchanger surface area (A_o) for the internal coil-in-tank exchanger used in Example 1 of the "Pump & Tube Sizing Examples." Select conservative values for q, U_o, and ΔT_{LM} from the ranges given in the guidelines above:

Assume $q = 180 \quad \frac{\text{Btu}}{\text{hr-ft}^2 \text{ of collector}}$

$U_o = 40 \quad \frac{\text{Btu}}{\text{hr-ft}^2 \text{ of exchanger} - {}^oF}$

$\Delta T_{LM} = 15^oF$

Therefore the estimated heat exchanger area (A_o) needed to transfer the heat delivered by two 4' x 8' flat-plate collectors with a collector area of 64 ft^2 is:

$$A_o = \frac{180\ (64)}{40\ (15)} = 19.2 \text{ ft}^2 \left(\text{or } \frac{0.30 \text{ ft}^2 \text{ exchanger}}{\text{ft}^2 \text{ collector}}\right)$$

EXAMPLE 2

Estimate the heat exchanger surface area (A_o) for the external, counter-flow exchanger used in Example 2 of the "Pump & Tube Sizing Examples." Select conservative values for q, U_o, and ΔT_{LM} from the ranges given in the guidelines above:

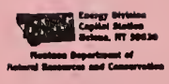
Assume $q = 180 \times \frac{\text{Btu}}{\text{hr-ft}^2 \text{ of collector}}$

$U_o = 200 \times \frac{\text{Btu}}{\text{hr-ft}^2 \text{ of exchanger - } ^oF}$

$\Delta T_{LM} = 15^oF$

The estimated heat exchanger area (A_o) needed to transfer the heat delivered by two 4' x 8' flat-plate collectors (64 ft^2) is:

$$A_o = \frac{180\ (64)}{40\ (15)} = 3.8\ ft^2 \left(\text{or } \frac{0.06\ ft^2 \text{ exchanger}}{ft^2 \text{ collector}}\right)$$



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MONTANA
SOLAR
HOT WATER

COMPARISON OF HEAT TRANSFER FLUIDS COMMONLY USED IN SOLAR COLLECTORS

Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

COMPARISON OF HEAT TRANSFER FLUIDS

Property	Distilled Water	60% Propylene Glycol/40% Water Mix	60% Ethylene Glycol/40% Water Mix	Brayco 888 Hydrocarbon Oil	Syltherm 444 Silicone Oil	Air
Cost	Low	Medium	Medium	Medium	High	Low
Color	Clear	Amber	Amber	Red	Clear	Clear
Toxicity	Low (with inhibitor)	Medium (with inhibitor)	High	Low	Low	Low
Potential for Leaks	Low	Medium	Medium	Medium	High	High
Viscosity	Low	Medium	Medium	High	High	Low
Compatible Elastomers	All	Butyl, EPDM Viton	Butyl, EPDM, Viton	Viton, Hydrin, Bunol-N	EPDM, Viton Fluorosilicone	All
Corrosion Potential	Medium	High	High	Low	Low	Low
Freeze Point (^{o}F)	NA	NA	NA	< - 80	< - 121	Does not freeze
Four Point (^{o}F)	NA	NA	NA	- 80	- 121	NA
Flash Point (^{o}F)	NA	214 (100% glycol)	250 (100% glycol)	325	525	NA
Autoignition Temperature ^{o}F	NA	NA	NA	635	NA	NA
Volume Expansion (%/^{o}F)	0.025	0.041	0.035	0.048	0.055	NA
Thermal Conductivity (Btu/hr-ft^2-^{o}F/ft) at 70^{o}F.	0.34	0.23	0.24	0.072	0.082	0.015
Density (lb/gal) at 60^{o}F	8.33	8.72	9.06	6.68	7.96	0.01
Heat Capacity (Btu/lb-^{o}F at 60^{o}F)	1.0	0.76	0.79	0.53	0.36	0.24
Volumetric Heat Capacity (Btu/gal-^{o}F)	8.33	6.63	7.16	3.54	2.86	0.002
Volumetric Flow Rate Necessary to to Deliver Same Heat (Relative to Water)	1.04	1.26	1.16	2.35	2.91	4165.00

Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

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Castrol INDUSTRIAL

Bray PRODUCTS

Brayco® 888 Solar Collector Heat Transfer Fluids

Design in Brayco® Solar Collector Heat Transfer Fluids
They offer you the ideal combination of benefits—
high specific heat, long service life,
freeze-proof, non-corrosive, low cost and more.

SYNTHESIZED HYDROCARBONS

The Bray Products Division of Burmah-Castrol lnc. — a proven leader in synthetic lubricants for the military and aerospace — has developed a series of fluids for the solar energy field.

These are the Brayco® 888 Solar Collector Heat Transfer Fluids — based on synthetic hydrocarbon technology, and produced by a proprietary chemical process.

DEVELOPMENTAL CONSIDERATIONS

The advent of new high-performance solar collectors put increased demands on the collector fluid. lt became obvious what was needed was a superior heat transfer fluid that met these five requirements:

- Universally available
- Moderately priced
- Incorporate all the qualities of the best solar collector fluids
- Require minimal retrofit of seals and hoses in old systems
- Offer a long service life

The *first* consideration was then to develop a fluid that could withstand high stagnation temperatures and also be freeze-proof. The *second* consideration was to develop a fluid which offered high specific heat and a long service life that would outperform water/glycol mixtures, mineral oils and silicones. The *third* consideration was to manufacture a synthetic fluid that would meet ASTM, SEIA, IAPMO, HUD, DOE, EUROPEAN, lSRAELl and all other world standards. The *fourth* consideration was to manufacture this fluid to be competitively priced with conventional fluids and lower in cost than silicone, glycol and all other synthetic fluids.

All these considerations were realized with added benefits of being non-corrosive, non-toxic, bio-degradable and engineered to perform for extended periods of time without fluid replacement.

BRAYCO® 888 FLUIDS ARE THE RESULT

Brayco 888 Solar Collector Heat Transfer Fluids demonstrate long service life, non-corrosivity, and high stagnation, temperature resistance — as shown by actual field performance and the corrosion and oxidation test specimens and sludge filter test results on the following page. Brayco fluids were compared with several other fluids used throughout the world and it was determined that Brayco Solar Collector Heat Transfer Fluids last longer and protect your system better.

PRODUCT DESCRIPTION

Brayco 888 and Brayco 888HF Solar Collector Heat Transfer Fluids are synthetic hydrocarbons derived from petroleum raw materials. Both Brayco 888 and 888HF contain a new proprietary additive package developed especially for this type of synthetic hydrocarbon base stock.

Because these fluids are produced by chemical synthesis, they offer many advantages over conventional mineral oils, glycol, silicone and other synthetic fluids used in solar collectors.

These advantages are:

High Specific Heat

Although lower than glycol-water mixtures, Brayco is higher than other synthetic hydrocarbons, and almost twice as high as the very expensive silicone fluids.

High Boiling Point

The initial boiling point is typically 40°F higher than other synthetic hydrocarbons and glycol type fluids.

High Flash Point

Flash point is 40°F above typical mineral, synthetic, and glycol solar collection fluids. The flash point for Brayco 888HF is 440°F.

Freeze Proof

Brayco 888 and 888HF have pour points below – 80°F for safe operation and excellent pumpability in cold climates without draindown.

Long Service Life

With Brayco fluids you can expect ten years of normal operation in your solar collector system without fluid replacement. We guarantee it. Refer to the Brayco 888 limited warranty on back page.

Fully Synthetic

Every component used in processing the Brayco fluids is synthetic. The resulting fluid is highly controlled and highly stable.

Cost-Effectiveness and Lower Cost

The cost-effectiveness of any operating solar system is the sum of its initial installed cost, the cost of maintaining the system during its effective lifetime, and the cost of failure caused by down time.

Brayco fluids demonstrate their cost effectiveness by being lower in initial cost, higher in specific heat, longer lasting, requiring less maintenance, exhibiting no corrosion or fluid breakdown at operating temperature, maintaining lower viscosity, and having lower freezing points than mineral oils, glycols, and most other synthetic fluids.

Non-Corrosive

Brayco 888 fluids have proven they help prevent corrosion problems, particularly those resulting from prolonged stagnations.

Non-Toxic

Laboratory tests show that both Brayco 888 and 888 HF have an oral toxicity LD_{50} rating in excess of 40 ml/kg, a Gosselin Rating of 1.

Both fluids are non-irritants to the eyes and skin, based on Consumer Product Safety Commission definition CFR 16, SS1500.3. ln addition, both fluids are 100% biodegradable and safe to operating and handle.

Normal Operating Temperature Range

Brayco 888* is designed to operate within the range of approximately – 65°F to 325°F and Brayco 888HF over the range of – 30°F to 400°F.

Actual operating temperature is a function of system design.

*Stagnation temperature. Brief periods of stagnation — such as occurs during system malfunction or vacation shutdown — to 400°F using Brayco 888 and 450°F for Brayco 888HF for an inert system.

Member Burmah Group

Corrosion/Oxidation Test Results

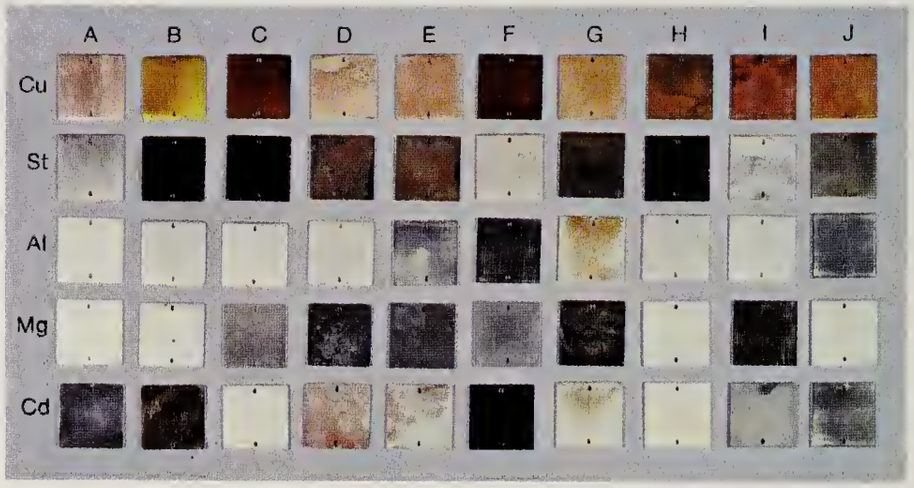
Comparison to typically recognized competitive products sold as Solar Collector Heat Transfer Fluids.

Corrosion and Oxidation Test Specimens

Federal Test Method 791B-5308 275°F for 168 hours, 100 ml. fluid with immersed metal specimens air blown at 5 liters/hour.

Average Metal Weight Loss, mg/cm²

A) Control Metals	
B) Brayco® 888	0.012
C) Brayco® 888HF	0.000
D) Synthetic Hydrocarbon ME-1	0.128
E) Synthetic Hydrocarbon ME-2	0.323
F) Silicone Oil	0.004
G) Propylene Glycol	0.288
H) Synthetic Hydrocarbon U-1	0.018
I) Modified Terphenyl	0.190
J) Non-aqueous Fluid	0.030

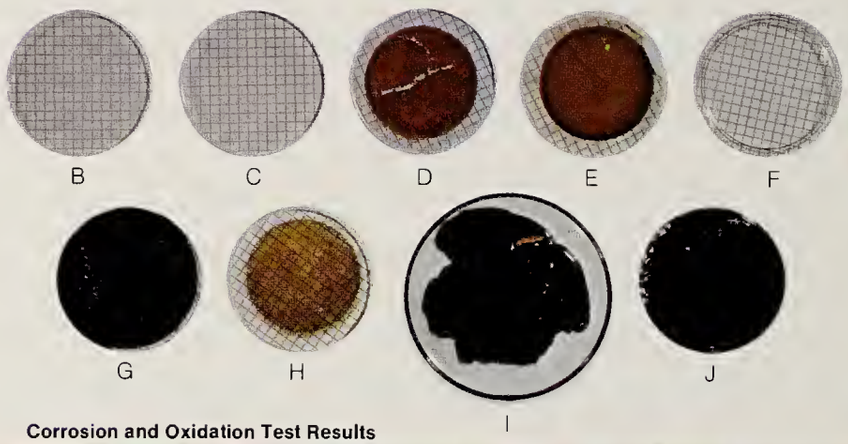


Corrosion Test Filter

Insolubles, 10 micron filter

Sludge,mg. per 100 ml.

B) Brayco® 888	0.00
C) Bracyo® 888HF	0.00
D) Synthetic Hydrocarbon ME-1	2.00
E) Synthetic Hydrocarbon ME-2	7.3
F) Silicone Oil	0.00
G) Propylene Glycol	0.25
H) Synthetic Hydrocarbon U-1	2.0
I) Modified Terphenyl	9.1
J) Non-aqueous Fluid	4.3



Corrosion and Oxidation Test Results

Solar Collector Heat Transfer Fluids	Brayco® 888 Synthetic Hydrocarbon	Brayco® 888HF Synthetic Hydrocarbon	Synthetic Hydrocarbon ME-1	Synthetic Hydrocarbon ME-2	Silicone Oil	Propylene Glycol	Synthetic Hydrocarbon U-1	Modified Terphenyl	Non-aqueous Fluid
Viscosity change @ 100°F	+2.6	+1.1	+236.6	+200.0	+0.7	+48.0	+3.1	+172.6	+9.6
Total acid no. change (Mg KOH/gm)	0.03	0.06	8.87	6.94	0.06	2.49	0.03	4.43	0.56
Sludge (Mg/100ml; 10 micron filter)	0.0	0.0	2.0	7.3	0.0	0.25	2.0	9.1	4.3
Metals, weight change									
Cu	+0.016	+0.024	−0.176	−0.336	+0.008	+0.096	−0.040	−0.216	+0.008
St	+0.016	0.000	−0.064	−0.272	−0.008	+0.032	−0.008	+0.752	−0.032
Al	−0.016	0.000	−0.008	+0.024	0.000	+0.104	−0.008	−0.008	−0.016
Mg	0.000	0.000	+0.184	+0.472	0.000	−0.112	0.000	−0.528	−0.008
Cd	−0.008	+0.008	−0.624	−0.360	−0.008	−0.464	−0.016	−0.008	−0.064

GENERAL CONCLUSION CORROSION AND OXIDATION TEST

The corrosion and oxidation test is an accelerated test which demonstrates 1) the long term corrosion effects on the internal surfaces of the metals used in the solar system and 2) the life expectancy of the heat transfer fluid being used.

The test results show that Brayco 888 and 888HF Solar Collector Heat Transfer Fluids *did not* corrode the metals and *did* retain their original properties at the end of the test. Most of the other fluids tested showed both corrosion to metals and drastic changes in their original properties. They chemically broke down under the test and would require replacement if originally installed in a solar collector system.

Fluid Comparative Chart

Bray PRODUCTS

Solar Collector Heat Transfer Fluids	ASTM Method	Brayco® 888 Synthetic Hydrocarbon	Brayco® 888HF Synthetic Hydrocarbon	Synthetic Hydrocarbon ME-1	Synthetic Hydrocarbon ME-2	Silicone Oil	Propylene Glycol	Synthetic Hydrocarbon U-1	Modified Terphenyl	Non-aqueous Fluid
API Gravity @ 60°F	D287	45.0	40.2	38.0	38.6	16.5	4 1	36.2	8.5	24.8
Specific Gravity	D287, Table 3	.805 (60°F)	.825 (60°F)	.835 (100°F)	.815 (100°F)	.946 (77°F)	1.03 (60°F)	.837 (68°F)	—	.900 (72°F)
Pounds Per Gallon @ 60°F	D287, Table 8	6.675	6.862	6.951	6.926	7 962	8.691	7.026	8.418	7.539
Flash Point, °F	D92	325	440	300	285	525	230	550	365	360
Fire Point, °F	D92	350	480	315	305	590	240	595	395	370
Specific Heat	D2766	≈ .55	≈ .55	≈ .55	≈ .55	≈ 37	≈ .70	≈ .55	—	—
0°F		.50	.50	—	—	—	—	—	—	—
50°F		.52	.52	—	—	—	—	—	—	—
75°F		.54	.54	—	—	—	—	—	—	—
100°F		.55	.55	.57	53	—	—	—	≈ 38	≈ .56
150°F		.58	58	—	—	.40	—	—	—	—
200°F		.60	.60	—	—	—	—	—	—	—
250°F		.62	62	—	—	—	—	—	—	—
300°F		.65	.65	—	—	—	—	—	.48	—
Viscosity, cs	D445									
– 65°F		1308	80000	Solid	Solid	220	Too Viscous	Solid	Solid	Solid
– 40°F		295	8500	51064	15005	116.7	14879	117490	Solid	Too Viscous
– 10°F		100	620	2700	1600	65	1500	12000	80000	2500
0°F		56.5	443	1870	825	55.8	861	6894	22945	1393
100°F		5.67	21.92	27.45	20.49	16.51	16.95	124.3	30.0	21.26
210°F		1.8	4.42	4.46	3.85	6.87	2.30	14.55	3.51	3.61
Viscosity Index	D2270	92	124	68	79	388	< 0	128	< 0	23
Boiling Point, °F	—	550	680	560	575	—	218	—	643	671
Color	—	Red	Red	Green	Amber	Clear	Straw	Clear	Clear	Red
Pour Point, °F	D97	– 80	< – 90	– 25	– 60	– 121	– 50	– 50	– 15	– 30
Freezing Point, °F	—	< – 80	< – 90	– 40	– 40	< – 100	– 30	– 50	– 18	– 40
Acid No. mg KOH/gm	D974	0.00	0.00	0.37	0 28	0.00	0.76	0.06	0.00	0.03
Cu Strip	D130	1a	1a	1a	1a	1a	1a	1a	1a	1a
H_20 KFR, PPM	D1744	8	17	206	91	139	—	124	95	52
Foam	D892									
1		0/0	0/0	380/0	90/0	0/0	0/0	620/140	50/0	320/0
2		0/0	0/0	30/10	20/10	10/0	0/0	50/0	20/0	30/0
3		0/0	0/0	310/0	80/0	0/0	0/0	380/20	220/0	270/0
Rubber Swell, "L", %	FTM 3603*	9.7	3.2	10.1	10.1	—	—	—	—	—
Evaporation loss, 22 hours @ 210°F, %	D972	4.6	0 6	15.8	14 8	0.03	0.8	0.02	—	—
Toxicity		No	No	No	No	No	No	No	No	No
Draize Index		0	0	—	—	—	—	—	—	—
Irritation Index	—	0	0	—	—	—	—	—	—	—
Oral L.D. 50, Gosselin rating		1	1	1	1	1	1	1	—	—
Autoignition Temp., °F	E659	635	730	—	—	—	—	—	705	824
Thermal Expansion Characteristics @ 60°F	—	4.8×10^{-4}	4.8×10^{-4}	0 033%/°F	0 033%/°F	0 053%/°F	—	0.0007 cc/cc °C	0 07%/°F	$4 0 \times 10^{-4}$
Thermal Conductivity, @ 300°F BTU/hr. (ft.) (°F/ft.)	—	0.0732	0.0732	0.0700	0.0700	0.0720	—	0.0710	0.0670	—
Normal Operating Temperatures	—	< –65°F to 325°F	– 30 °F to 400°F	N/A	N/A	–50°F to 400°F	0°F to 300°F	to 450°F	15°F to 650°F	N/A

NOTE: Most of the tests were run by Bray Products, with results shown being the actual values reported. Values from tests not run by Bray were taken from the manufacturer's product literature. Omitted values indicate information not found in available literature.

* Test Method

Member Burmah Group

Application Story in The Capitol

Brayco® 888 was chosen over many other heat transfer fluids for the Fort Lincoln Senior Village in Washington, D.C. (above and right).

PRODUCT APPLICATION

All over the world, Brayco 888 and 888HF Solar Collector Heat Transfer Fluids are being used in closed loop active solar collector systems for residential, industrial, and insti—tutional applications.

For example, Brayco 888 is being used as the heat transfer medium for a huge domestic hot water solar system in Washington, D.C.

Fort Lincoln Senior Village uses Brayco 888 in their 10 story, 188 dwelling building. Built in 1977 by Forest City Dillon, Inc., this is believed to be the first and largest solar collection system in the Capitol.

The Fort Lincoln system supplies 65% of the annual energy consumption associated with heating domestic hot water, including water for a clinic and large kitchen-cafeteria.

The system has over 2,500 square feet of panels on the roof of the building. The pump, heat exchanger, piping, valving, and automatic controls are all conventional equipment. Hot water is stored in an insulated tank with a holding capacity of 3,200 gallons.

Selection criteria for the Fort Lincoln complex were stringent. The fluid specified would have to withstand severe climatic changes — from winter freezing to summer stagnation temperatures. The fluid would also have to be non-corrosive to metals, non-toxic, compatible with construction materials, and have a long service life.

The table below represents the study that was performed to select a fluid that met all requirements. Brayco 888 was tested along with water, ethylene glycol, propylene glycol, silicone, and paraffinic-based oils.

Brayco was selected because Brayco 888 met the stringent conditions.

Today, the Fort Lincoln Senior Village is realizing substantial economies in fuel costs for heating water and the solar system is performing year round without any problems.

In over six years of operation, no maintenance has been required and there has been no change in the fluid's original properties.

This application story again emphasizes that Brayco fluids will retain their superior heat transferring properties for years and years — even in the most demanding of environments.

Fort Lincoln Senior Village Solar Collector Fluid Selection Criteria

Solar Collector Heat Transfer Fluids	Brayco® 888	Brayco® 888HF	Water	Ethylene Glycol/Water	Propylene Glycol/Water	Silicone	Aromatic Mineral Oil	Naphthenic Mineral Oil	Paraffinic Mineral Oil
Specific Heat	.55	.55	1.0	.70	.70	.37	.45	.45	.45
Freezing Point	−80°F	−80°F	32°F	−50°F	−50°F	−80°F	−60°F	−70°F	+15°F
High Temperature Oxidation	excellent	excellent	NA	very poor	very poor	very good	very poor	fair	good
Toxicity	low	low	none	high	low	low	medium	low	low
High Temperature Compatibility with Cu, Al	excellent	excellent	fair	poor	very poor	good	fair	fair	good
Corrosion	none	none	poor	poor	poor	low	low	low	low
Flash Point	medium	high	NA	low	low	high	low to medium	low to medium	medium
Attack of Asphalt Shingles	low	low	none	none	none	low	high	medium	low
Cost	medium	medium	very low	medium	medium	very high	low	low	low

System Design Engineering Data

The following graphs and illustrations are provided for solar system design purposes when using BRAYCO 888 Solar Collector Heat Transfer Fluid. Any additional engineering information which is not included can be provided upon request.

ELASTOMER COMPATABILITY

Solar systems which require elastomers such as "O" rings in pumps, bladders in expansion tanks, seals in valves, etc., should be evaluated as to the elastomer material which they contain.

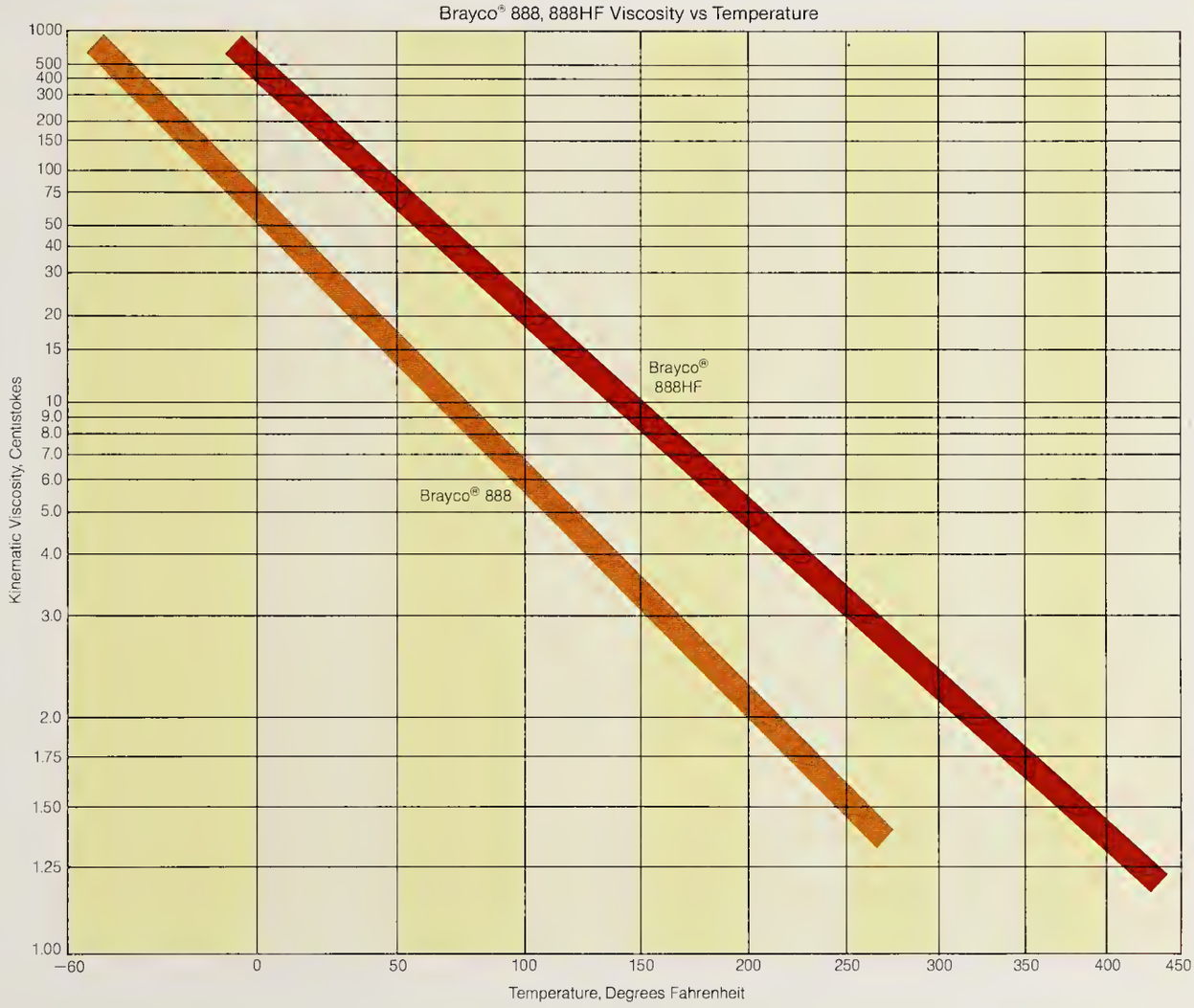
BRAYCO 888 and 888HF are hydrocarbon type fluids and will affect certain types of elastomer materials. We suggest that all elastomers in system components be compatible with hydrocarbon type fluids.

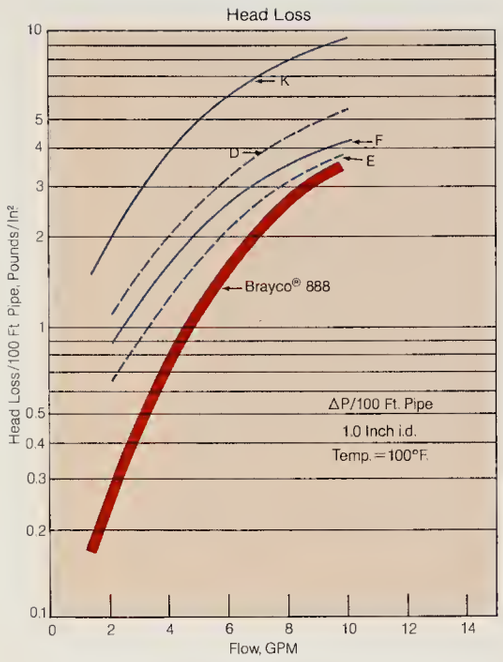
Some examples of compatible elastomers are VITON, HYDRIN, NITRILE, NEOPRENE, various types of BUNA-N COMPOUNDS, and FLUORO-SILICONE. Any uncertainties concerning elastomer compatability should be discussed with the Bray Products Marketing Department.

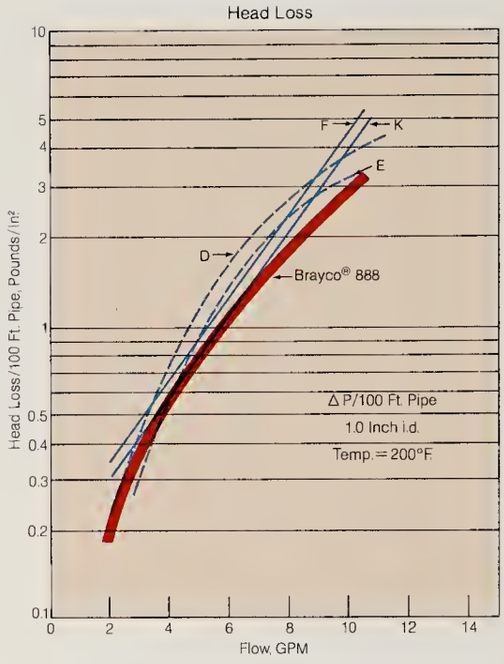
For more information about Brayco Solar Collector Heat Transfer Fluids

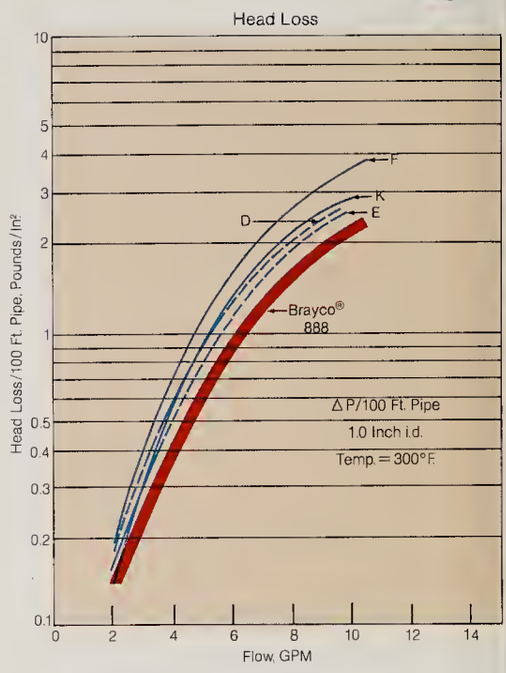
Contact Bray Products Division to learn how you can enjoy the many advantages Brayco 888 and Brayco 888HF offer over conventional mineral oils, glycols, silicones, and other synthetic fluids.

Remember, once you put Brayco in your systems, you'll never have to be concerned about fluid replacement again — guaranteed!



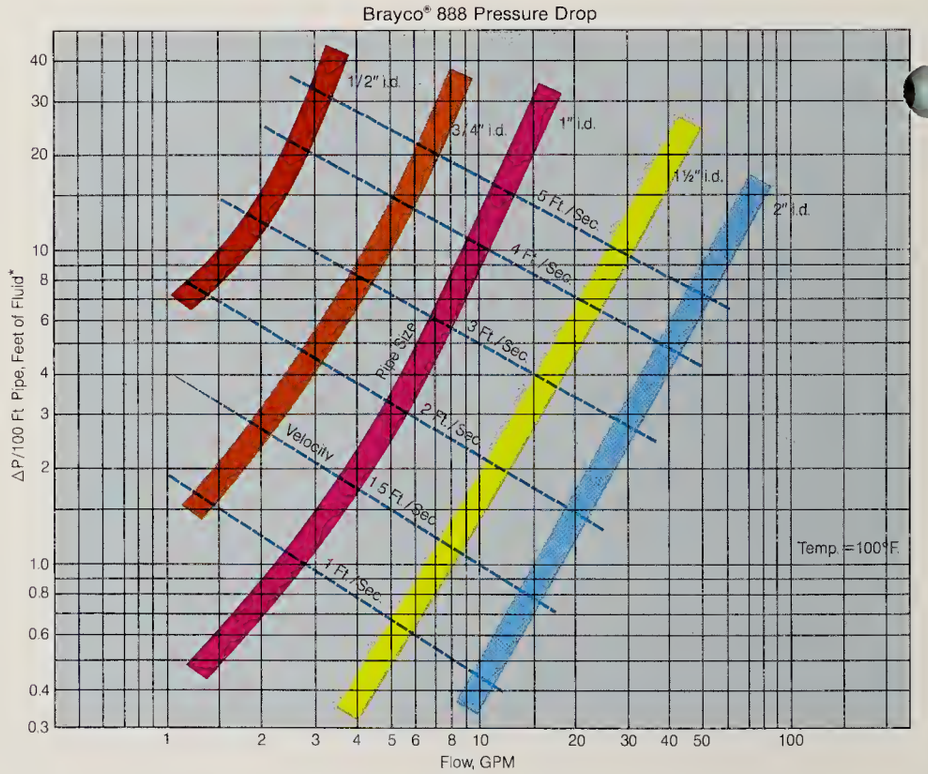


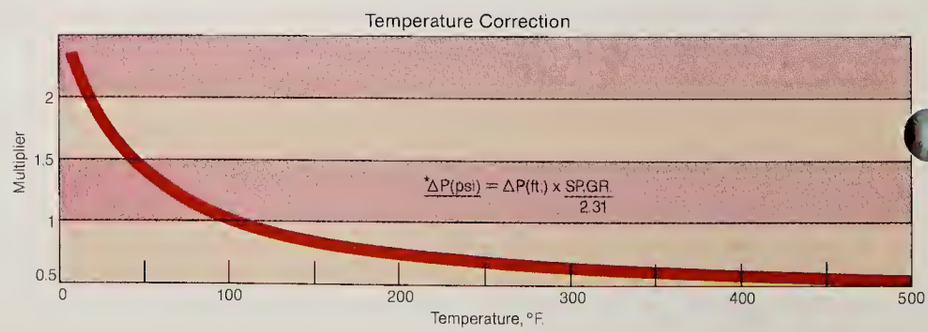




Competitive Head Loss Legend.

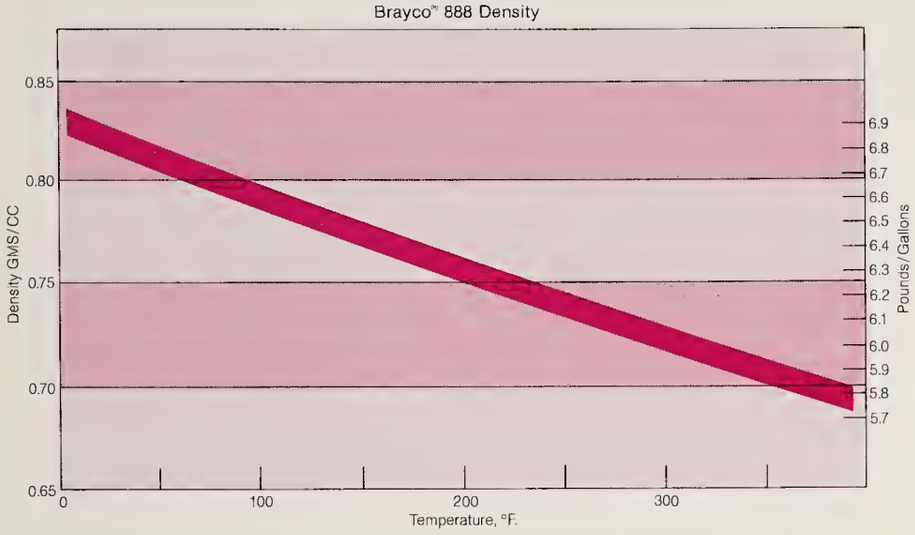
D) Synthetic Hydrocarbon ME-1
E) Synthetic Hydrocarbon ME-2
F) Silicone Oil
K) Mineral Oil





Bray PRODUCTS

Brayco® 888 Density



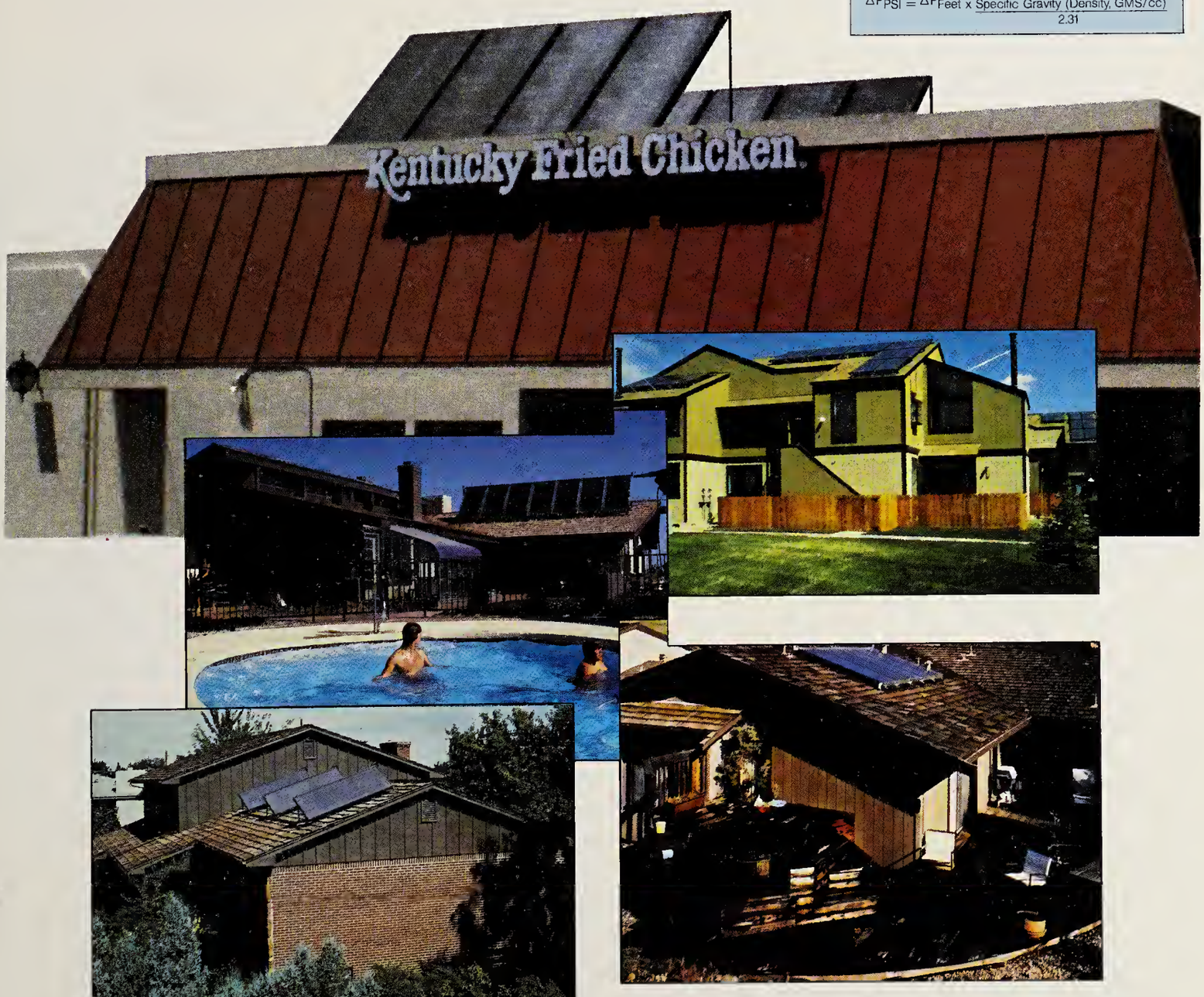
Equivalent Length, Fittings

Pipe Fittings	Feet Added to System (approx.)
Check Valve	25
Elbow (90°)	2
Gate Valve	2
Globe Valve	60
Plug Cock	6
Reducer	2
Swage	2
Tee	3
Tee	9
Tee	12
Vessel Inlet	8
Vessel Outlet	4

For Changes in Elevation

$$\Delta P_{Total} = \Delta P_{Pipe\ Friction} + \Delta P_{Fittings} + \Delta P_{Elevation}$$

$$\Delta P_{PSI} = \Delta P_{Feet} \times \frac{\text{Specific Gravity (Density, GMS/cc)}}{2.31}$$



Typical Solar Heat Transfer Fluid applications.
Photos courtesy of Novan Energy Inc.

Glossary of Solar Terms

A

ABSORBENT The less volatile of the two working fluids used in an absorption cooling device.

ABSORBER The blackened surface in a solar collector that absorbs the solar radiation and converts it to heat energy.

ACID NUMBER The specific quantity of KOH (potassium Hydroxide) required to counter balance the acid characteristics of a fluid sample. Though acidity is not, of itself, necessarily harmful, an increase in acidity may be indicative of fluid deterioration.

ACTIVE SYSTEM A solar heating or cooling system that requires external mechanical power to move the collected heat.

AIR-TYPE COLLECTOR A solar collector that uses air as the heat transfer fluid.

API GRAVITY Weight per-unit-volume relationship. Specific gravity is expressed as the ratio of the weight of a volume of fluid at a designated temperature, to the weight of an equal volume of water also at a designated temperature. The designated temperature is often 60°F (15°C) in both cases. The higher the specific gravity, the heavier the material.

AUTOIGNITION TEMPERATURE The minimum temperature at which a combustible fluid will burst into flame without an extraneous ignition source.

AUXILIARY HEAT The extra heat provided by a conventional heating system for periods of cloudiness or intense cold, when a solar heating system cannot provide enough.

B

BTU, OR BRITISH THERMAL UNIT The quantity of heat needed to raise the temperature of 1 pound of water 1°F.

C

COEFFICIENT OF THERMAL EXPANSION The amount of expansion of a fluid caused by an increase in temperature of 1°F.

COLLECTOR Any of a wide variety of devices (flat-plate, concentrating, vacuum tube, greenhouse, etc.) used to collect solar energy and convert it to heat.

COLLECTOR EFFICIENCY The ratio of heat energy extracted from a collector to the quantity of solar energy striking the cover, expressed in percent.

CONCENTRATING COLLECTOR A device that uses reflective surfaces to concentrate the sun's rays onto a small area, where they are absorbed and converted to heat energy.

CONDUCTION The transfer of heat energy through a material by the motion of adjacent atoms and molecules.

CONVECTION The transfer of heat energy from one location to another by the motion of fluids that carry the heat.

COVER PLATE A sheet of glass or transparent plastic that sits above the absorber in a flat-plate collector.

D

DIFFUSE RADIATION Sunlight that is scattered from air molecules, dust, and water vapor and comes from the entire sky vault.

DIRECT METHODS Techniques of solar heating in which sunlight enters a house through the windows and is absorbed inside.

DIRECT RADIATION Solar radiation that comes straight from the sun, casting shadows on a clear day.

DOUBLE-GLAZED Covered by two panes of glass or other transparent material.

E

EUTECTIC SALTS A group of materials that melt at low temperatures, absorbing large quantities of heat and then, as they re-crystallize, release that heat. One method used for storing solar energy as heat.

EVAPORATION LOSS A value which indicates the amount of evaporation loss of a fluid after it has been subjected to 210°F for 22 hours in an evaporation cell (the evaporation loss is calculated from the loss in weight of the sample).

F

FIRE POINT The lowest temperature at which a combustible fluid, under specified conditions, vaporizes sufficiently rapidly to form an air vapor mixture above its surface and which burns continuously when ignited by a small flame.

FLASH POINT The lowest temperature at which vapors arising from the oil will ignite momentarily, i.e. flash on application of a flame (ignition source) under special conditions.

FLAT-PLATE COLLECTOR A solar collection device in which sunlight is converted to heat on a plane surface, usually made of metal or plastic. A heat transfer fluid is circulated through the collector to transport heat to be used directly or to be stored.

FORCED CONVECTION The transfer of heat by the flow of warm fluids, driven by fans, blowers, or pumps.

H

HEADER The pipe that runs across the top (or bottom) of an absorber plate, gathering (or distributing) the heat transfer fluid from (or to) the grid of pipes that runs across the absorber surface.

HEAT EXCHANGER A device, such as a coiled copper tube immersed in a tank of water, that is used to transfer heat from one fluid to another through an intervening metal surface.

HEAT PUMP A mechanical device that transfers heat from one medium (called the heat source) to another (the heat sink), thereby cooling the first and warming the second.

HEAT SINK A medium or container to which heat flows (see heat pump).

HEAT STORAGE A device or medium that absorbs collected solar heat and stores it for periods of inclement or cold weather.

I

INDIRECT SYSTEM A solar heating or cooling system in which the solar heat is collected outside the building and transferred inside using ducts or piping and, usually, fans or pumps.

INSOLATION The total amount of solar radiation — direct, diffuse and reflected — striking a surface exposed to the sky.

INSULATION A material with high resistance or R-value that is used to retard heat flow.

INTEGRATED SYSTEM A solar heating or cooling system in which the solar heat is absorbed in the walls or roof of a dwelling and flows to the rooms without the aid of complex piping or ducts.

L

LIFE-CYCLE COSTING An estimating method in which the long-term costs such as energy consumption, maintenance, and repair can be included in the comparison of several system alternatives.

LIQUID-TYPE COLLECTOR
A collector with a liquid as the heat transfer fluid.

N

NOCTURNAL COOLING The cooling of a building or heat storage device by the radiation of excess heat into the night sky.

P

PASSIVE SYSTEM A solar heating or cooling system that uses no external mechanical power to move the collected solar heat.

PERCENTAGE OF POSSIBLE SUNSHINE The percentage of daytime hours during which there is enough direct solar radiation to cast a shadow.

PHOTOVOLTAIC CELLS Semiconductor devices that convert solar energy into electricity.

POUR POINT The lowest temperature at which a fluid will flow.

R

RADIANT PANELS Panels with integral passages for the flow of warm fluids, either air or liquids. Heat from the fluid is conducted through the metal and transferred to the rooms by thermal radiation.

REFRIGERANT A liquid such as FREON that is used in cooling devices to absorb heat from surrounding air or liquids as it evaporates.

RETROFITTING The application of a solar heating or cooling system to an existing building.

RISERS The flow channels or pipes that distribute the heat transfer liquid across the face of an absorber.

S

SELECTIVE SURFACE An absorber coating that absorbs most of the sunlight hitting it but emits very little thermal radiation.

SPECIFIC HEAT Water has been established at 1.000, which is used to arrive at the specific heat of liquids. It is the ratio of heat contained in one pound of liquid to the heat contained in one pound of water. For example, Silicone type liquids have a specific heat of about 0.350 because they absorb and retain only about 1/3 as many units of heat as water.

T

THERMAL CAPACITY The quantity of heat needed to warm a collector up to its operating temperature.

THERMAL RADIATION
Electromagnetic radiation emitted by a warm body.

TILT ANGLE The angle that a flat collector surface forms with the horizontal.

TRICKLE-TYPE COLLECTOR
A collector in which the heat transfer liquid flows down open channels in the front face of the absorber.

TUBE-IN-PLATE ABSORBER
An aluminum or copper sheet metal absorber plate in which the heat transfer fluid flows through passages formed in the plate itself.

TUBE-TYPE COLLECTOR
A collector in which the heat transfer liquid flows through metal tubes that are wired, soldered, or clamped to the absorber plate.

U

UNGLAZED COLLECTOR A collector with no transparent cover plate.

V

VISCOSITY A measure of the resistance of a fluid to a continuous flow. From the standpoint of application, it is the most important property of fluid because it measures the change in body these fluids undergo due to a change in temperature. For example, most fluids become more viscous or resist flow when cooled down and become less viscous or flow easier when heated.

Burmah-Castrol Inc.
Bray Products Division
2698 White Road
Irvine, CA 92714
(714) 660-9414

Brayco Limited Warranty

If the Brayco® 888 Solar Collector Heat Transfer Fluids freeze, boil, breakdown or corrode during the first four years after installation, Bray Products Division of Burmah-Castrol Inc. herein called Bray Products will replace the fluid free of charge. During the next six years, Bray Products will replace the fluid upon payments of a charge calculated upon the retail price of the fluid at the time of replacement and the number of years the fluid has been installed. This warranty is based on determination of fluid characteristics by federal testing method No. 791B-5308. The warranty does not apply to conditions which result from improperly installed fluid, failure to provide reasonable maintenance, misuse, negligence, contamination, or use beyond recommended operating and stagnation temperature ranges.

LIMITATIONS

It is expressly agreed that the duration of this limited warranty is ten years and that all implied warranties, whether of fitness for a particular purpose or of merchantability, shall also be limited to ten years. SOME STATES DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LASTS, SO THE ABOVE LIMITATION MAY NOT APPLY TO YOU.

It is also expressly agreed that Bray Products exclusive obligation under this limited warranty and under any implied warranties, whether of fitness for a particular purpose or of merchantability, shall be the replacement as stated above of Brayco 888 or 888HF Solar Collector Heat Transfer Fluid and that buyer's exclusive remedy under this limited warranty and any implied warranties, whether of fitness for a particular purpose or of merchantability, shall be the right to receive such replacement fluid.

It is further expressly agreed that Bray Products will have no obligation under this limited warranty or under any implied warranty, whether of fitness for a particular purpose or of merchantability, for consequential or incidental damages nor for any injury or damage to the solar system in which Brayco 888 or 888HF may be installed or any component parts thereof. SOME STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION OR EXCLUSION MAY NOT APPLY TO YOU. THIS WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS, AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH VARY FROM STATE TO STATE.

Qualification For Brayco 888 Limited Warranty

The Brayco 888 Limited Warranty is conditional and to qualify for the warranty benefits, Brayco 888 Solar Collector Heat Transfer Fluids must be properly installed in solar heating systems (that meet Bray Products' standards.) They must also be installed by professional contractors, authorized dealers, or wholesalers who have qualified for the Brayco 888 Limited Warranty Program. For information on how to qualify for the Brayco 888 Limited Warranty Program or for information regarding qualified contractors, dealers, and wholesalers, write Bray Products Division of Burmah-Castrol Inc.

To receive replacement quantities of Brayco 888 under this warranty, either the owner of the solar system in which the Brayco 888 is installed or the professional contractor, authorized dealer or wholesaler that installed or sold the Brayco 888 must submit a written claim to Bray Products, addressed as follows:

Burmah-Castrol Inc.
Bray Products Division
2698 White Road
Irvine, CA 92714

Additionally, upon request, the person or entity submitting the warranty claim must supply a sample of the failed fluid to Bray Products.

Member Burmah Group

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ENGINEERING AND OPERATING GUIDE FOR DOWFROST AND DOWTHERM SR-1 HEAT TRANSFER FLUIDS

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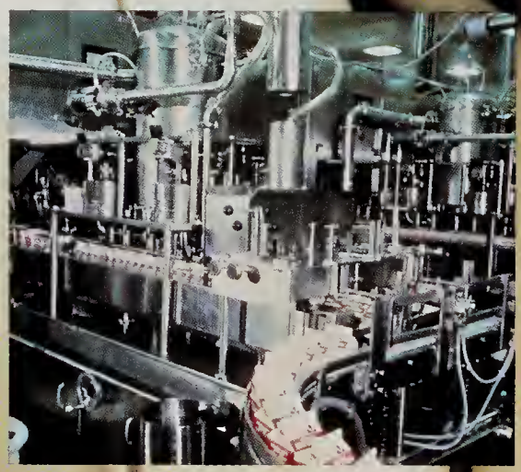


WHY DOWFROST & DOWTHERM SR-1 INHIBITED GLYCOLS ARE BETTER HEAT TRANSFER MEDIUMS THAN OTHER FLUID AND NON-FLUID METHODS

More engineers and operators, more often, are specifying DOWFROST* and DOWTHERM* SR-1 inhibited glycols in water for secondary cooling and heat transfer applications; for freeze and burst protection of pipes; and for various deicing, dehumidifying, and defrosting applications. Why? Because compared to alternative fluids and to non-fluid methods, inhibited glycols can improve process efficiency, reduce costs, or both. Here are some specific examples.

Plain water can be used only in applications between 32°F and 212°F. And it contains impurities which can become corrosive when in contact with air. DOWFROST and DOWTHERM SR-1, on the other hand, are highly effective heat transfer media between −40°F and 250°F. And because they are inhibited glycols, they protect against corrosion.

With uninhibited salt brine solutions, corrosion can be an even greater problem, particularly in open systems. Typically, these systems require frequent maintenance, periodic shutdown, draining, cleaning, and addition of new brine. As for inhibited salt brines, they often contain a toxic sodium chromate or dichromate inhibitor, which requires frequent surveillance and adjustment. Those aren't problems with DOWFROST and DOWTHERM SR-1 inhibited glycols. The inhibitor is low in toxicity, easily maintained, and can be easily replenished as needed. The fluids are low in corrosivity. And system shutdowns for cleaning are few and far between compared to inhibited salt brines. That represents a significant savings in maintenance and labor.

Compared to oils, aqueous solutions of DOWFROST and DOWTHERM SR-1 are lower in viscosity. As a result, pumping costs are lower. They also offer higher specific heats so heat transfer is more efficient. In addition, they are non-flammable. And in most cases, solutions of DOWFROST and DOWTHERM SR-1 cost less than oils.

Compared to steam, these inhibited glycols are less corrosive and easier to control. And systems are easier and less expensive to operate.

Compared to automotive antifreezes, DOWTHERM SR-1 and DOWFROST are less toxic. They will not foul heat exchanger surfaces, and they offer longer system life.

Solutions of DOWFROST and DOWTHERM SR-1 inhibited glycols aren't as flammable as alcohol. They won't thermally degrade as fast as glycerine. They aren't as toxic as ammonia. And often, they're less expensive, less toxic, and offer more efficient heat transfer than aromatic organics, methanol, and silicones.

Uninhibited glycols oxidize in the presence of air. And at high temperatures, oxidation is even faster. Oxidation forms organic acids, and the acids lower the pH of the glycol solution. Result: Potential for corrosion. Inhibited glycols, on the other hand, maintain a stable pH (buffering) by reacting with any organic acid formed. That protects against corrosion. The inhibitor also passivates the surface of the metal, providing continuous protection.

Compared to non-liquid methods, DOWFROST and DOWTHERM SR-1 don't use as much energy as hot air/gas, electric, or air-dry coil defrosting systems. And it's not necessary to interrupt production for defrosting operations with these inhibited glycols. In freezing and chilling operations, the inhibited glycols can provide faster freezing, and low installation, maintenance, and labor costs.

So no matter what heat transfer fluid or method you're using or considering, you'll find that none offer all the advantages of DOWTHERM SR-1 and DOWFROST.

* Trademark of The Dow Chemical Company
©The Dow Chemical Co., 1982

Photo courtesy G. Heilman Brewing Co.

Service and technical support: major advantages in specifying DOW inhibited glycols

The Dow Chemical Company has long been involved in heat transfer technology in industrial and food-related applications. Beyond merely supplying fluids, Dow offers the depth of experience, technical know-how, and willingness to bring these to bear in helping design and troubleshoot field applications.

When you deal with Dow, you can count on support from a number of departments whose insight can be valuable. These would include, among others, Microbiology, Construction Materials, and Heat Transfer. Your local Dow representative can arrange for technical service people to assist you as needed with many aspects of system preparation and operation.

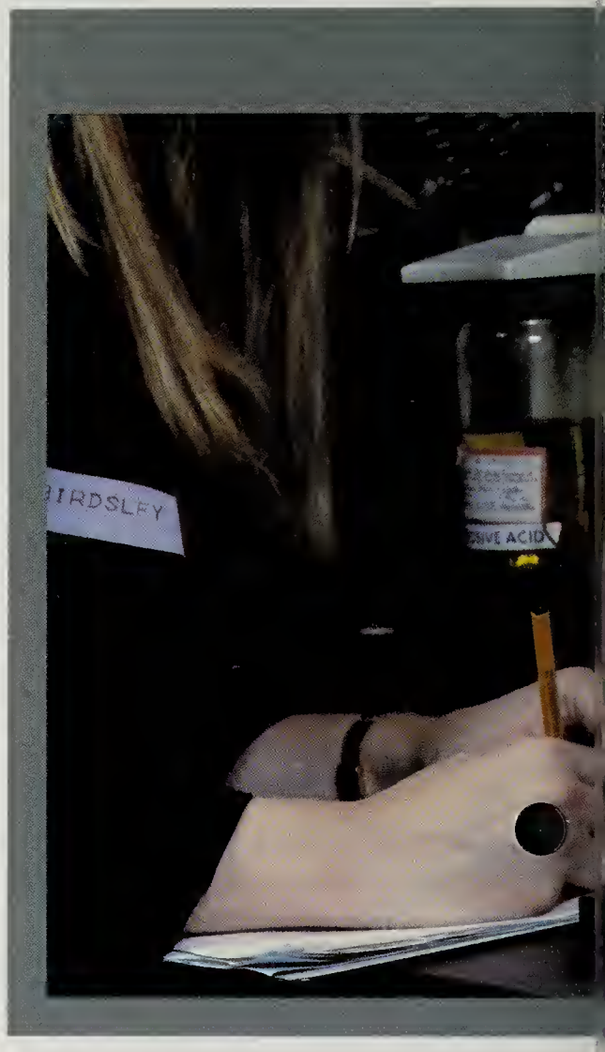
This combination of quality product and high-level technical service and support are the basic reasons behind the success of Dow products in the applications described on pages 10 and 11.

Examples of how the "Dow difference" has helped others

Here are six examples of how Dow's extensive technical and service capabilities have solved system design and operation problems.

1. By providing comparisons of heat transfer efficiency parameters and start-up/operating horsepower requirements, Dow personnel helped engineers at a major automotive company design a large heat recovery loop. That enabled them to size equipment properly for the system and select the most efficient fluid.

2. Dow's microbiologists provided data for a meat packing customer showing how glycol concentration, fluid temperature, and sludge build-up relate to bacterial growth. The data allowed engineers to change operating conditions and adjust glycol concentration to inhibit that bacterial growth.



3. Dow analysts helped a customer in the chemical industry cut capital expenditures in the construction of a secondary heat transfer system and fluid storage tank. Different materials of construction were recommended which were fully compatible with DOWTHERM SR-1 inhibited glycol, yet far less costly than those originally planned.

4. A Dow technical service representative made suggestions on the design of a small pipeline tracing system for a detergent manufacturer. This resulted in extended lifetime of DOWTHERM SR-1 and reduced operational costs.

5. Dow's analytical chemists provided a chemical processor with a method for analyzing and monitoring chloride contamination in the glycol as a result of the process. This helped the customer determine when contamination exceeded the acceptable limit, so that leaks could be repaired and corrosion minimized.

6. Dow Industrial Cleaning Services Division (now Dowell Industrial Service) was contracted by a brewery to clean three old, corrosion-ridden, salt brine chilling systems. The customer then charged the system with DOWFROST inhibited propylene glycol. Dow now analyzes the fluid periodically so the customer knows precisely when to replenish either the fluid or inhibitor for continued smooth operations.

Free analytical testing service

The Dow Chemical Company offers free sample analysis of the fluid on an annual basis, as a courtesy to customers whose systems contain 250 gallons or more of DOWFROST or DOWTHERM SR-1 heat transfer fluid.

The analysis determines both the glycol and inhibitor levels. And based on information you provide about your system (such as capacity, operating temperature range, and desired freeze protection), you can learn whether or not the fluid is meeting your requirements. If not, proper adjustments of the fluid are also recommended. This service is discussed in more detail on page 40 of this brochure.

A BASIC DESCRIPTION OF DOWFROST AND DOWTHERM SR-1 HEAT TRANSFER FLUIDS

DOWFROST heat transfer fluid is an inhibited propylene glycol that's clear and colorless. DOWTHERM SR-1 heat transfer fluid is an inhibited ethylene glycol that's clear and bright pink.

DOWFROST and DOWTHERM SR-1 inhibited glycols are practically odorless, and easily mixed with water. DOWTHERM SR-1 has a moderate level of toxicity; DOWFROST is very low in toxicity. Both fluids have good heat transfer characteristics, offer good freeze protection, and have low volatility. Both are hygroscopic at low temperatures, meaning they attract moisture from the surrounding atmosphere. Both are non-flammable in solutions up to 80% glycol in water.

COMPARISON OF TYPICAL PHYSICAL PROPERTIES OF AQUEOUS SOLUTIONS OF DOWFROST AND DOWTHERM SR-1 HEAT TRANSFER FLUIDS

These properties can be considered typical of the product, but should not be regarded as specifications.

		% Glycol By weight					
		20%		40%		60%	
Physical property	Temp	DOWTHERM SR-1	DOWFROST	DOWTHERM SR-1	DOWFROST	DOWTHERM SR-1	DOWFROST
Thermal conductivity BTU/(hr) (ft^2)(°F/ft)							
	20°F	.270	.264	.228	.215	.194	.175
	200°F	.327	.318	.269	.252	.223	.198
Specific heat BTU/lb °F							
	20°F	.936	.965	.838	.887	.734	.770
	200°F	.954	.987	.914	.944	.837	.882
Viscosity (Centipoise)							
	20°F	4	5.3	7	20	16	50
	200°F	.47	.5	.6	.7	.89	1.1
Density (g/ml)							
	20°F	1.034	1.028	1.067	1.053	1.102	1.071
	200°F	0.986	0.978	1.012	0.989	1.035	0.995

NOTE: Specific engineering data for other concentrations and temperatures for DOWFROST and DOWTHERM SR-1 are shown on pages 16 through 23.

	DOWFROST Heat Transfer Fluid	DOWTHERM SR-1 Heat Transfer Fluid
Composition (% by weight)		
Total glycols (minimum)	95.5	95.5
Inhibitors and water	4.5	4.5
Dye	None	Pink
Specific gravity at 60/60°F	1.0500-1.0600	1.125-1.135
pH of 1:1 dilution	9.0-10.0	9.0-9.6
Reserve alkalinity, minimum (ASTM D1121)	9.8 ml.	11.0 ml.

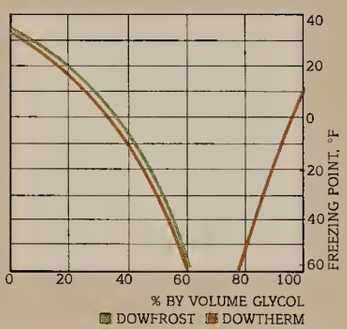
PRODUCT SPECIFICATIONS

Methods of analysis and complete sales specifications available on request.

TYPICAL PHYSICAL PROPERTIES OF AQUEOUS SOLUTIONS OF DOWFROST

These properties can be considered typical of the product, but should not be regarded as specifications.

FREEZING POINTS OF AQUEOUS SOLUTIONS OF DOWFROST AND DOWTHERM SR-1



Freeze Point It should be noted that the freeze points for glycols are the temperature *at which the ice crystals first form.* Below these temperatures, a slushy solution exists which will permit flow. However, as the temperature decreases, the slush becomes more viscous until freezing eventually occurs.

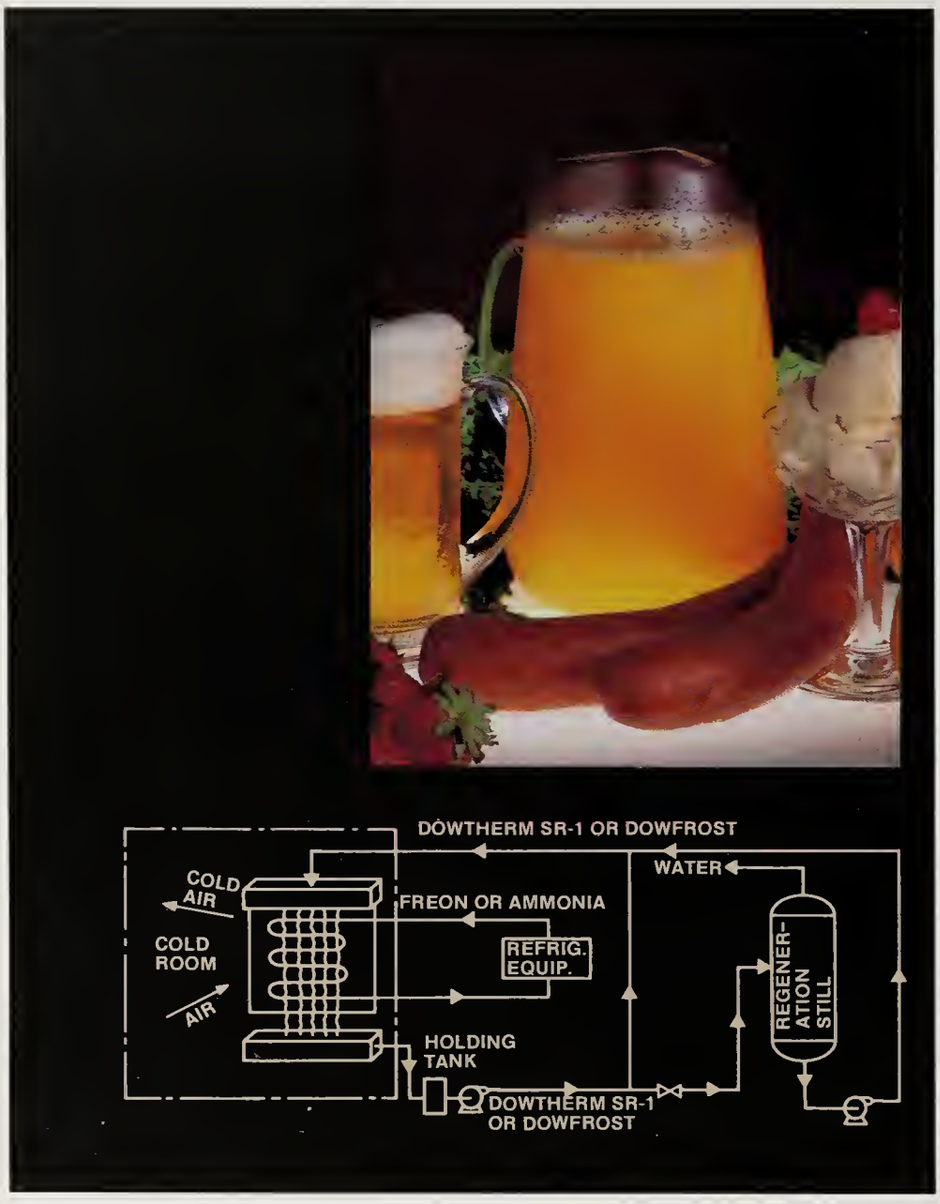
Weight % Propylene Glycol	Volume % Propylene Glycol	Freeze Point °F	Refractive Index N_D 77°F	Degree Brix	Boiling Point °F @760MM Hg
20	19.4	19.9	1.3565	15.4	213°F
21	20.4	19.0	1.3575	16.0	
22	21.4	18.0	1.3586	16.7	
23	22.4	17.0	1.3598	17.4	
24	23.4	16.0	1.3611	18.4	
25	24.4	15.0	1.3621	18.8	214°F
26	25.3	14.0	1.3632	19.6	
27	26.4	13.0	1.3643	20.2	
28	27.4	12.0	1.3654	20.8	
29	28.4	11.0	1.3664	21.4	
30	29.4	9.1	1.3674	22.0	216°F
31	30.4	8.0	1.3685	22.7	
32	31.4	7.0	1.3700	23.6	
33	32.4	6.0	1.3714	24.4	
34	33.5	4.0	1.3729	25.3	
35	34.4	3.0	1.3742	26.1	217°F
36	35.5	1.0	1.3755	26.9	
37	36.5	0	1.3765	27.5	
38	37.5	−2.0	1.3775	28.0	
39	38.5	−4.0	1.3785	28.5	
40	39.6	−5.0	1.3796	29.1	219°F
41	40.6	−7.0	1.3806	29.6	
42	41.6	−9.0	1.3816	30.2	
43	42.6	−11.0	1.3826	30.7	
44	43.7	−13.0	1.3837	31.3	
45	44.7	−15.0	1.3847	31.8	220°F
46	45.7	−17.0	1.3857	32.4	
47	46.8	−19.0	1.3868	33.0	
48	47.8	−22.0	1.3878	33.5	
49	48.9	−25.0	1.3889	34.1	
50	49.9	−29.0	1.3899	34.7	222°F
51	50.9	−31.0	1.3911	35.5	
52	51.9	−33.0	1.3922	35.9	
53	53.0	−37.0	1.3936	36.6	
54	54.0	−40.0	1.3947	37.2	
55	55.0	−43.6	1.3961	38.0	223.5°F
56	56.0	−46.0	1.3968	38.4	
57	57.0	−50.0	1.3981	39.1	
58	58.0	−53.0	1.39911	39.6	
59	59.0	−57.0	1.4002	40.3	
60	60.0	−60.0	1.4012	40.7	225°F

Weight % Ethylene Glycol	Volume % Ethylene Glycol	Freeze Point °F	Refractive Index N_D 77°F	Degree Brix	Boiling Point °F @760MM Hg
20	18.1	17.0	1.3525	13.0	216°F
21	19.2	16.5	1.3536	13.7	
22	20.1	16.0	1.3546	14.3	
23	21.0	14.0	1.3555	14.8	
24	22.0	13.0	1.3565	15.4	
25	22.9	12.0	1.3575	16.0	218°F
26	23.9	11.0	1.3585	16.6	
27	24.8	10.0	1.3590	17.0	
28	25.8	9.0	1.3605	17.7	
29	26.7	8.0	1.3615	18.5	
30	27.7	7.0	1.3625	19.0	220°F
31	28.7	5.0	1.3636	19.7	
32	29.6	4.0	1.3645	20.3	
33	30.6	2.0	1.3656	20.9	
34	31.6	1.0	1.3666	21.5	
35	32.6	0.0	1.3677	22.2	221°F
36	33.5	−1.0	1.3686	22.8	
37	34.5	−3.0	1.3696	23.4	
38	35.5	−4.0	1.3707	24.0	
39	36.5	−5.0	1.3718	24.6	
40	37.5	−8.0	1.3728	25.2	222°F
41	38.5	−9.0	1.3729	25.9	
42	39.5	−11.0	1.3750	26.5	
43	40.5	−13.0	1.3760	27.2	
44	41.5	−15.0	1.3770	27.7	
45	42.5	−17.0	1.3780	28.2	224°F
46	44.0	−20.0	1.3796	29.1	
47	45.0	−22.0	1.3806	29.6	
48	46.0	−24.0	1.3816	30.2	
49	47.1	−26.0	1.3828	30.8	
50	48.0	−28.0	1.3837	31.3	225°F
51	49.1	−31.0	1.3848	31.9	
52	50.1	−35.0	1.3858	32.5	
53	51.2	−36.0	1.3869	33.1	
54	52.2	−38.0	1.3880	33.6	
55	53.2	−43.0	1.3889	34.1	227°F
56	54.3	−45.0	1.3899	34.7	
57	55.3	−50.0	1.3909	35.2	
58	56.3	−52.0	1.3919	35.7	
59	57.4	−54.0	1.3930	36.4	
60	58.4	−58.0	1.3939	36.8	230°F

TYPICAL PHYSICAL PROPERTIES OF AQUEOUS SOLUTIONS OF DOWTHERM SR-1

These properties can be considered typical of the product, but should not be regarded as specifications.

WHERE DOWFROST AND DOWTHERM SR-1 HAVE ALREADY PROVEN EFFICIENT AND COST EFFECTIVE



Because DOWFROST and DOWTHERM SR-1 inhibited glycols offer advantages that other fluids and methods don't, they're used in a variety of applications. Here are nineteen of them.

DEFROSTING, DEICING, AND DEHUMIDIFYING

1. Refrigeration coil defrosting Cold DOWFROST in 35-50% concentration, or DOWTHERM SR-1 in 40-50% concentration, is sprayed directly on refrigeration coils, either continuously or intermittently. The glycol spray removes any frost on the coils. In addition, the hygroscopic action of the glycol absorbs condensation on the coils to prevent further frost formation, and the inhibitor helps prevent corrosion.

2. Cold room dehumidifying Because high humidity supports mold and bacteria growth, food processing and warehousing companies spray chilled DOWFROST or DOWTHERM SR-1 through the air which flows over refrigeration coils. This not only absorbs moisture to maintain low relative humidity and prevent frost, it filters dust and other particulates from the air.

3. Conveyor roller defrosting In freezing tunnels, cold DOWTHERM SR-1 in 40-55% concentration is sprayed directly on rollers to prevent frost formation. As a result, there's no belt slippage or production interruptions.

FREEZE AND BURST PROTECTION OF PIPES

4. Heating, Ventilating, and Air Conditioning (HVAC) systems DOWFROST or DOWTHERM SR-1 inhibited glycol added to an HVAC system lowers the freeze-point of water to reduce the potential for freeze-up or bursting of pipes. Draining the system or running it year round, and problems associated with those practices, are eliminated. The inhibited glycol helps prevent corrosion of the metal, and can last 12 to 18 years in the system when properly maintained.

5. Fire hydrants and sprinkler systems A 50% concentration of DOWFROST in equipment lowers the freeze-point of water and reduces problems with winter freeze-up and burst hardware.

SECONDARY COOLING

6. Cooling liquid foods In liquid food processing, a 30-50% solution of cold DOWFROST inhibited glycol is circulated through coils submerged in or wrapped around tanks containing food products. Because DOWFROST offers a lower temperature range than water, liquids can be cooled and bottled faster, sometimes with less foaming. That can increase production rates.

7. Fermentation cooling DOWFROST in 30-50% concentration can be chilled in a primary refrigeration unit, then circulated through coils of fermentation, wort, or yeast bulk storage tanks. DOWFROST offers lower temperatures than water to permit recovery of CO_2 generated during fermentation, which can be used later in the bottling process.

8. Process chilling As a secondary coolant, a 30-50% concentration of DOWFROST or DOWTHERM SR-1 is cooled in a primary chiller, then pumped through coils submerged in or wrapped around process tanks. The glycol's temperature is controllable, so equipment is easy to operate.

9. Immersion freezing of wrapped foods Wrapped foods totally immersed in a 40-50% solution of DOWFROST freeze quickly so production rates increase. Because of this fast-freezing, many products look better and last longer on the shelf.

10. Packaging of carbonated beverages Following fermentation, carbonated beverages such as champagnes are submerged in a chilled bath of DOWFROST inhibited glycol prior to decanting and rebottling. This helps prevent loss of carbonation. For other carbonated beverages such as beer, cold DOWFROST is pumped through coils submerged in or wrapped around process tanks to reduce carbonation loss.

11. Ice-making To freeze water quickly and increase production, trays of water are lowered into tanks filled with refrigerated and agitated DOWFROST or DOWTHERM SR-1 in 40-50% concentration.

12. Ice skating rinks By chilling and circulating a 40-55% solution of DOWTHERM SR-1 through pipes beneath or on top of a rink floor, water freezes quickly into a smooth sheet of ice.

13. Plastic bottle blow-molding DOWFROST or DOWTHERM SR-1 inhibited glycol in 30-50% concentration is preferred to water in this application because it can achieve lower temperatures. By circulating chilled inhibited glycol through a mold, faster cooling results. That speeds production. Rapid cooling also provides a better quality product because plastic flash can be trimmed quickly and cleanly.

SECONDARY HEAT TRANSFER

14. Process/pipeline tracing Compared to steam tracing, liquid tracing with DOWFROST or DOWTHERM SR-1 in 30-50% concentration provides several benefits. With an inhibited glycol, only one steam trap is required versus one every 100 feet with steam. And unlike steam, which must be fed continuously to the system, the glycol is heated only when the process temperature drops below a pre-determined point. That lowers operating costs. Because steam is available only above 212°F, there's a danger of overheating and decomposing sensitive products. Liquid tracing with the inhibited glycol provides dependable temperature control over a wide range of temperatures.

Compared to electrical tracing, liquid tracing with DOWFROST or DOWTHERM SR-1 requires far less energy and thus lowers operating costs.

15. Heat recovery As DOWFROST or DOWTHERM SR-1 inhibited glycol in 30-50% concentration flows through a heat exchanger, it extracts heat from the fluid or gas waste heat source. The heated glycol is then pumped to a separate system to heat air, water, or other mediums.

16. Indirect air/gas heating After a 30-50% solution of DOWFROST or DOWTHERM SR-1 is heated in a conventional heat exchanger, it can then be used in various heating or drying applications. Applications for DOWFROST include drying barley malt and other food products. Applications for DOWTHERM SR-1 include pre-heating air coming into boilers and paper drying.

17. Solar heating A 30-50% solution of DOWFROST or DOWTHERM SR-1 freeze-protects water used in conventional solar collectors. As the sun heats the fluid, it's pumped elsewhere in the building where it heats air or water.

18. Snow melting systems A solution of 30-40% DOWTHERM SR-1 is heated in a heat exchanger, then pumped through tubing to keep paved surfaces above freezing temperatures. As a result, snow and ice melt on contact.

19. Refrigeration warehouse floor heating A solution of 30-50% DOWTHERM SR-1 is heated in a heat exchanger, then pumped through tubing to prevent the soil beneath the floor from freezing and causing frost-heave.

GENERAL DESIGN, EQUIPMENT, AND HEAT TRANSFER FLUID CONSIDERATIONS

This section is intended to point out what considerations should be given to DOWFROST and DOWTHERM SR-1 heat transfer fluids and the systems where they are used. Keep in mind, these are only general considerations. If you have a particular problem or question, you may want to take advantage of the technical service and support offered by The Dow Chemical Company. Your local Dow representative will be glad to arrange it all for you.

Materials of construction

Standard materials can be used with DOWFROST or DOWTHERM SR-1 heat transfer fluid. Steel, cast iron, copper, brass, solder, and plastic piping materials are all generally acceptable. DOWFROST or DOWTHERM SR-1 can also be used with aluminum at temperatures below 250°F. At temperatures above 250°F, use of aluminum is not recommended because the inhibitors do not fully protect the aluminum components in the system. Galvanized steel is not recommended in most cases because the zinc could react with the inhibitor in glycols, causing precipitation of components and release of hydrogen gas, particularly above 100°F.

Centrifugal pumps are commonly used with solutions of DOWFROST and DOWTHERM SR-1. Reciprocating pumps are necessary where fluids must be pumped at high head pressures. Pumps can be made of ordinary steel since the fluids are inhibited.

Piping valves and fittings can also be of ordinary steel. Schedule 10 piping will withstand normal pumping pressures.

Typically the same type of pump packing or mechanical seal used for water may be used with solutions of DOWFROST or DOWTHERM SR-1. Packing and seal manufacturers should be consulted for materials appropriate to your application and operating temperature.

Solutions of DOWTHERM SR-1 and DOWFROST are also generally compatible with most plastics and elastomers. Generally any material which can be used with uninhibited glycols may be used with DOWFROST and DOWTHERM SR-1.

Bypass filters are recommended for removal of foreign solids. Filters made of non-absorbent cotton, fiber, or cellulose-type media have been used successfully.

Using dissimilar metals in a system is not recommended because it may result in galvanic, "two-metal", corrosion. This type of corrosion can occur in electrolytic solutions when dissimilar metals (referencing the galvanic series) are in contact with or near each other. (An example of dissimilar metals would be aluminum directly connected to copper.) Solutions of DOWFROST or DOWTHERM SR-1 inhibited glycols are better than plain water, but neither could fully protect against galvanic corrosion of dissimilar metals electrically coupled in a system.

Effective temperature range

DOWFROST inhibited glycol has an effective operating temperature range of −28°F to 250°F, while DOWTHERM SR-1 inhibited glycol is effective from −40°F to 250°F. At temperatures below their lowest points, the fluids' increased viscosities (> 200 centipoise) can make them impractical to use without larger pumps.

At the upper end of the operating range, a maximum bulk temperature of 250°F is recommended, with film temperatures not to exceed 300°F. Above these temperatures two factors present problems. First, as with any water-based system, vapor pressure will increase rapidly above 300°F. Smooth operating without localized boiling or "vapor lock" becomes difficult despite maintaining pressure on the system.

Second, thermal degradation of the fluid is a problem. Glycol oxidation occurs in the presence of air at any temperature. The higher the temperature, the faster the oxidation. To minimize the oxidation rate, a closed system is recommended wherever possible. At temperatures above 150°F, nitrogen padding is also recommended. Although the fluids can tolerate brief exposures to temperatures up to 350°F, oxidation and degradation of both glycol and inhibitor become excessive with extended exposure above 300°F.

It should be noted that within the recommended operating range, film temperature at the wall of the heat exchanger should be no more than 25°F to 50°F higher than the bulk temperature. This helps to assure long fluid life.

Flammability

When mixed with water, neither DOWFROST nor DOWTHERM SR-1 are flammable since they have no measurable flash point (Pensky-Martens Closed Cup) in concentrations up to 80% glycol. DOWFROST inhibited glycol, to which no water has been added, has a flash point of 214°F and a fire point of 220°F (Cleveland Open Cup). DOWTHERM SR-1, to which no water has been added, has flash and fire points of 250°F.

Film coefficients of inhibited glycols and water

Solutions of DOWFROST and DOWTHERM SR-1 inhibited glycols have heat transfer properties different from those of plain water. These glycol solutions typically have lower film coefficients under equivalent flow conditions.

This may affect the design and operation of your system, depending on factors such as the heat transfer coefficient of the material being heated or cooled. For a complete discussion and related data on this subject, see page 25 of this brochure.

Efficiency versus concentration

To obtain peak heat transfer efficiency while providing full freeze-protection, avoid using excess concentrations of DOWFROST or DOWTHERM SR-1 in water. Generally, when the fluid is used either for freeze-protection or in secondary cooling applications, the concentration required would have a freeze point about 5°F lower than the lowest anticipated temperature. For burst-protection, when slush or ice crystals in the fluid is not a problem, slightly lower (~5-10%) concentrations can be adequate. Rarely is it necessary to use concentrations higher than 50-55% glycol in water. The less glycol used, the higher the relative heat transfer efficiency of the solution.

For optimum corrosion protection, the minimum concentration of either DOWFROST or DOWTHERM SR-1 in water should be 30%. If operating at lower concentrations is desired, consult your Dow technical representative for information relating to inhibitor adjustment.

Expansion factor

Like all fluids, solutions containing DOWFROST or DOWTHERM SR-1 inhibited glycol expand as the temperature increases. Expansion tanks should be sized to allow about 4% greater expansion than for plain water in the same temperature range. See page 16 for discussion of density and how to calculate exact volume expansion figures.

Also note that as temperatures drop below the freeze point of a glycol solution, ice crystals begin to form. This causes the solution to expand and the slush will flow to available expansion volume. The lower the temperature, the greater the expansion. However, when it gets cold enough so that glycol crystals form, it will then begin to contract. At very low temperatures, the entire mass freezes solid.

Regulatory status regarding the use of inhibited glycols in food-related applications

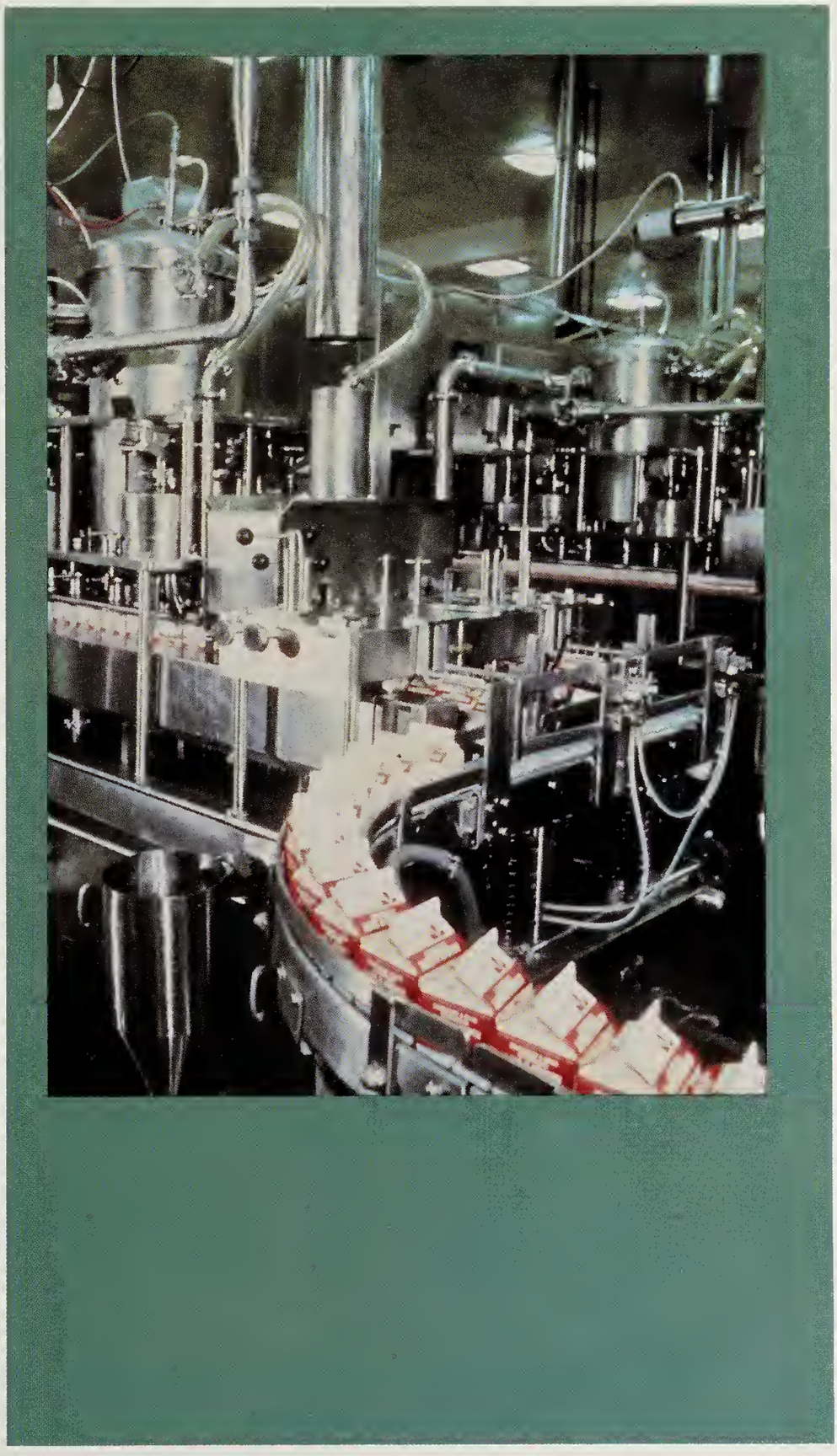
Solutions of DOWFROST are widely used in the food industry as secondary coolants in beverage processing, immersion freezing, refrigeration coil defrosting and other applications. The Dow Chemical Company does not recommend DOWFROST be used as a direct food additive. However, its low toxicity, odor, and taste make it suitable for various food processing applications. As with any fluid used in food processing, good manufacturing and handling procedures are required.

DOWTHERM SR-1 inhibited glycol is selected by the food industry for defrosting freezer coils where temperatures are too low to use propylene glycol-based fluids. It is also used in secondary heat transfer applications up to 250°F. DOWTHERM SR-1 should not be used where direct contact with food is possible.

DOWFROST inhibited glycol has been approved by United States Department of Agriculture (U.S.D.A.) for both defrosting refrigeration coils and for immersion-freezing of wrapped meats, poultry, and meat products in plants operated under Federal Meat Inspection. DOWTHERM SR-1 has received approval by the United States Department of Agriculture for defrosting refrigeration coils assuming direct contact with the meat product is avoided.

The Food and Drug Administration (F.D.A.) approves individual chemicals only, not proprietary products (tradenames). The two ingredients in DOWFROST heat transfer fluid are generally recognized as safe by the Food and Drug Administration as a food additive under Part 182 of the Food Additive Regulations. The regulation for propylene glycol is 21 CFR 182.1666; for dipotassium phosphate, 182.6285. The propylene glycol and dipotassium phosphate in DOWFROST meet the requirements of these regulations.

As is sometimes required for Grade A dairies or meat packers, a letter certifying the appropriate use and quality of DOWFROST or DOWTHERM SR-1, along with copies of the approval or acceptance letters from the United States Department of Agriculture or the Food and Drug Administration, is available to a customer on request.



PHYSICAL PROPERTIES AND ENGINEERING DATA FOR DOWFROST AND DOWTHERM SR-1

The next 8 pages contain specific information on DOWFROST and DOWTHERM SR-1 heat transfer fluids in table and graph forms. This data will help you select one of the two fluids, based on your system design and operating requirements.

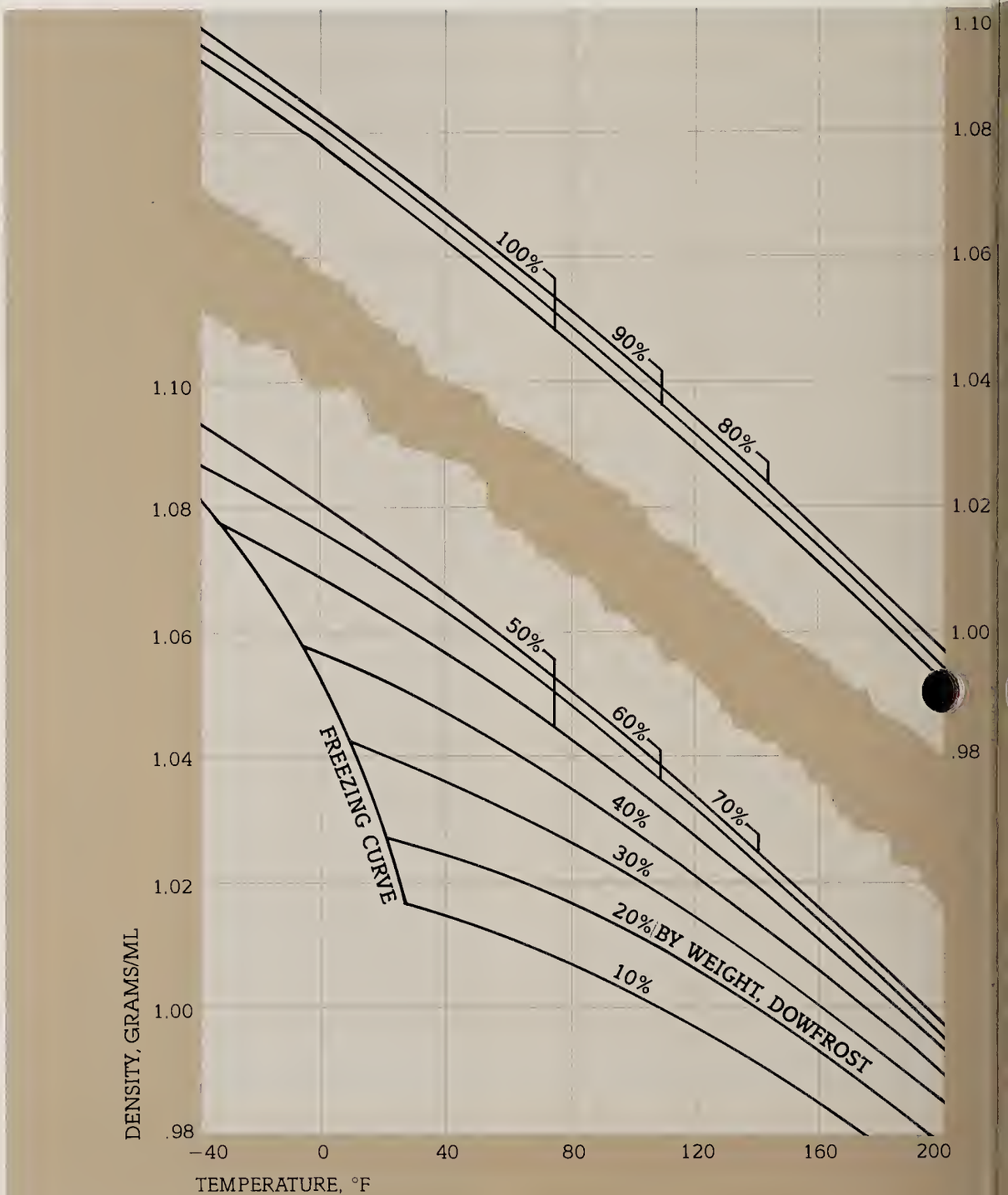
Again, if you have any problems or questions, your Dow representative can arrange for our technical service people to assist you.

Weight %	Volume % Glycol DOWFROST	Volume % Glycol DOWTHERM SR-1
0	0.0	0.0
5	4.8	4.4
10	9.6	8.9
15	14.5	13.6
20	19.4	18.1
25	24.4	22.9
30	29.4	27.7
35	34.4	32.6
40	39.6	37.5
45	44.7	42.5
50	49.9	48.0
55	55.0	53.2
60	60.0	58.4
65	65.0	62.8
70	70.0	68.3
75	75.0	73.6
80	80.0	78.9
85	85.0	84.3
90	90.0	89.7
95	95.0	95.0
100	100.0	100.0

WEIGHT PERCENT VERSUS VOLUME PERCENT OF DOWFROST AND DOWTHERM SR-1 IN SOLUTIONS

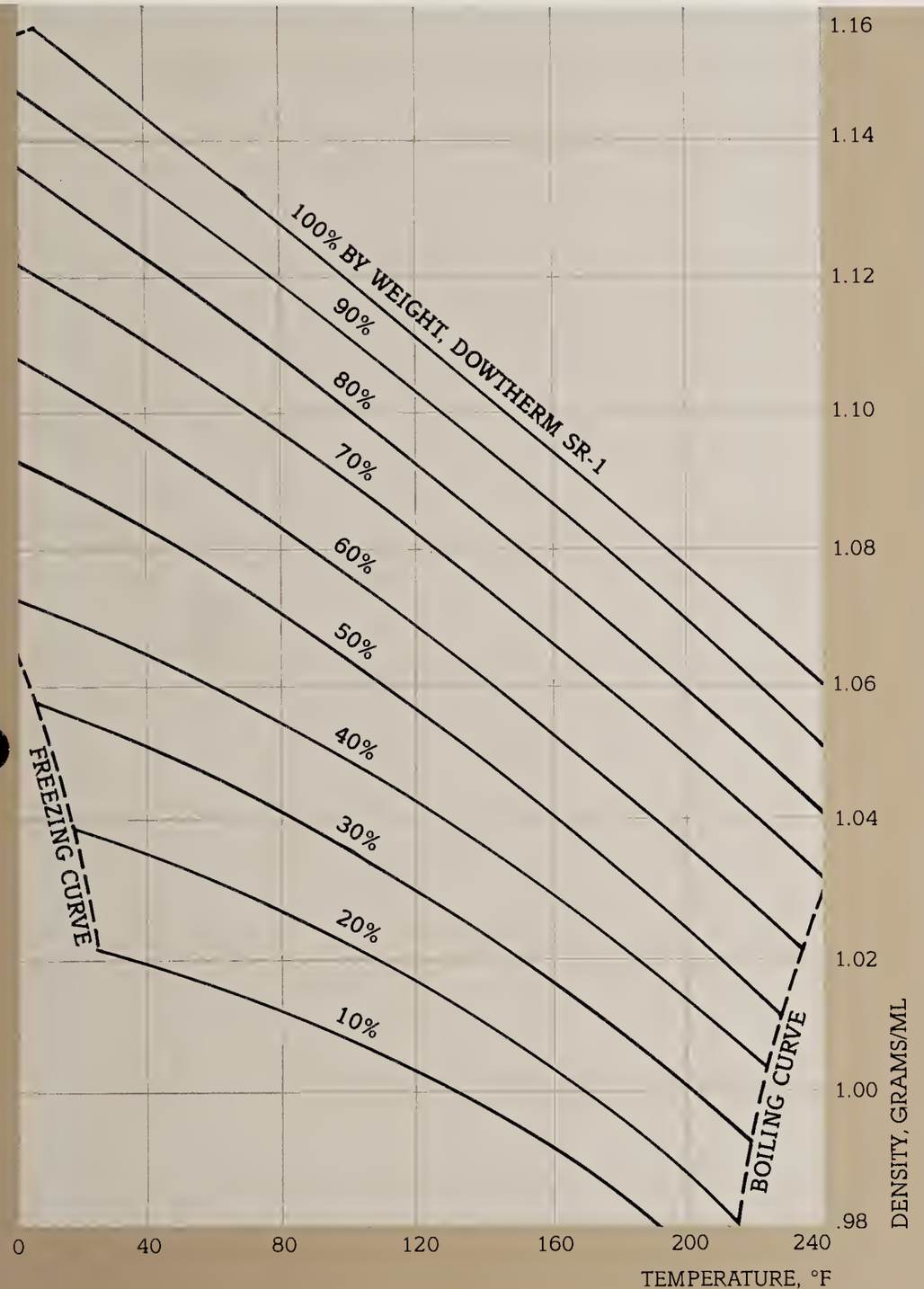
Density is the weight-per-unit-volume of a mass. Density of glycol solutions vary with temperature and concentration.

This graph shows that the densities of solutions of DOWFROST inhibited glycol and water may be the same for two concentrations. Therefore, density alone is not a reliable method to determine the concentration of a solution of DOWFROST. On the other hand, density *can* be used to determine



DENSITIES OF AQUEOUS SOLUTIONS OF DOWFROST

(NOTE: Curves for this chart represent DOWFROST; all others are propylene glycol.)



DENSITIES OF AQUEOUS SOLUTIONS OF DOWTHERM SR-1

(NOTE: Curves for this chart represent DOWTHERM SR-1; all others are ethylene glycol.)

the concentration of a solution of DOWTHERM SR-1 provided the temperature of the solution is taken into account.

The data provided here show densities of given solutions. It may also be desirable to know the specific gravities at certain temperatures. The specific gravity can be obtained by dividing the density of the glycol or glycol-water solution by the density of water. Densities, and therefore specific gravities, vary with temperature; hence it is necessary to indicate the temperature of both the glycol and the water. Specific gravities may be expressed at various temperatures, as follows:

$$\text{Specific gravity of DOWTHERM SR-1 at "x"°F/"y"°F *} = \frac{\text{Density of DOWTHERM SR-1 at "x"°F}}{\text{Density of water at "y"°F}}$$

For example, the specific gravity of 50% (wt) solution of DOWTHERM SR-1, the density of which is 1.067 g/ml at 77°F, when compared to water of density 0.9965 g/ml at 77°F, could be calculated as follows:

$$\text{Sp.Gr. at } 77°\text{F}/77°\text{F} = \frac{1.067}{0.9965} = 1.071$$

The weight per gallon of a given solution is determined as follows:

Density at t°F x 8.345 = lb/gal at t°F

For example, weight per gallon at 77°F of a 50% (wt) solution of DOWFROST:
1.044 x 8.345 = 8.71 lbs/gal
DOWTHERM SR-1:
1.067 x 8.345 = 8.90 lbs/gal

Volume changes resulting from heating or cooling glycol solutions may be calculated from the density data. For example, in heating 10,000 lbs. of a 50% solution of DOWTHERM SR-1 from 77°F to 140°F, the increase in volume will be:

$$\frac{10{,}000 \text{ lbs } (140°\text{F})}{8.74 \text{ lbs/gal}} - \frac{10{,}000 \text{ lbs } (77°\text{F})}{8.90 \text{ lbs/gal}} =$$

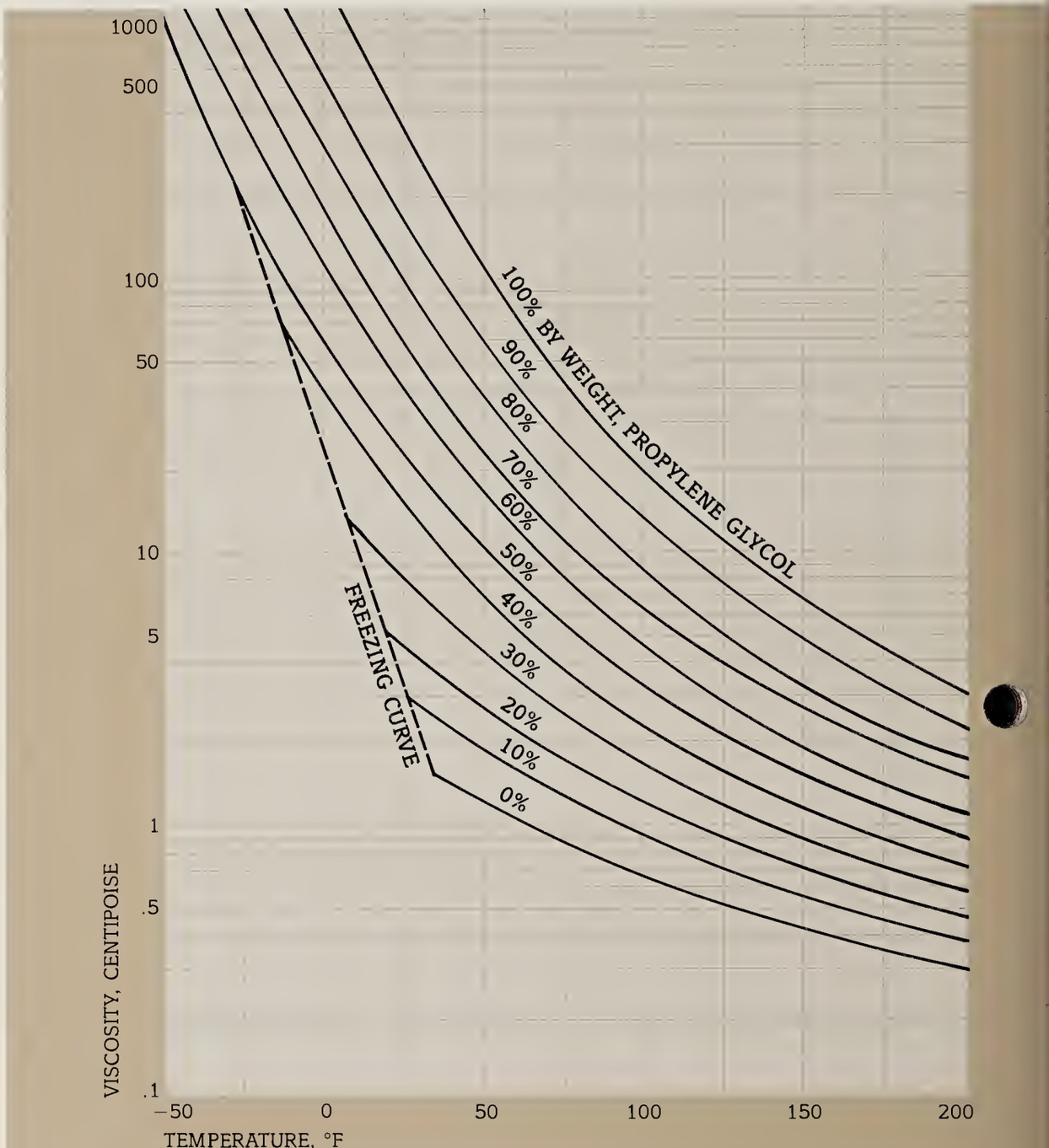
1144.2 gals − 1123.6 gals = 20.6 gals

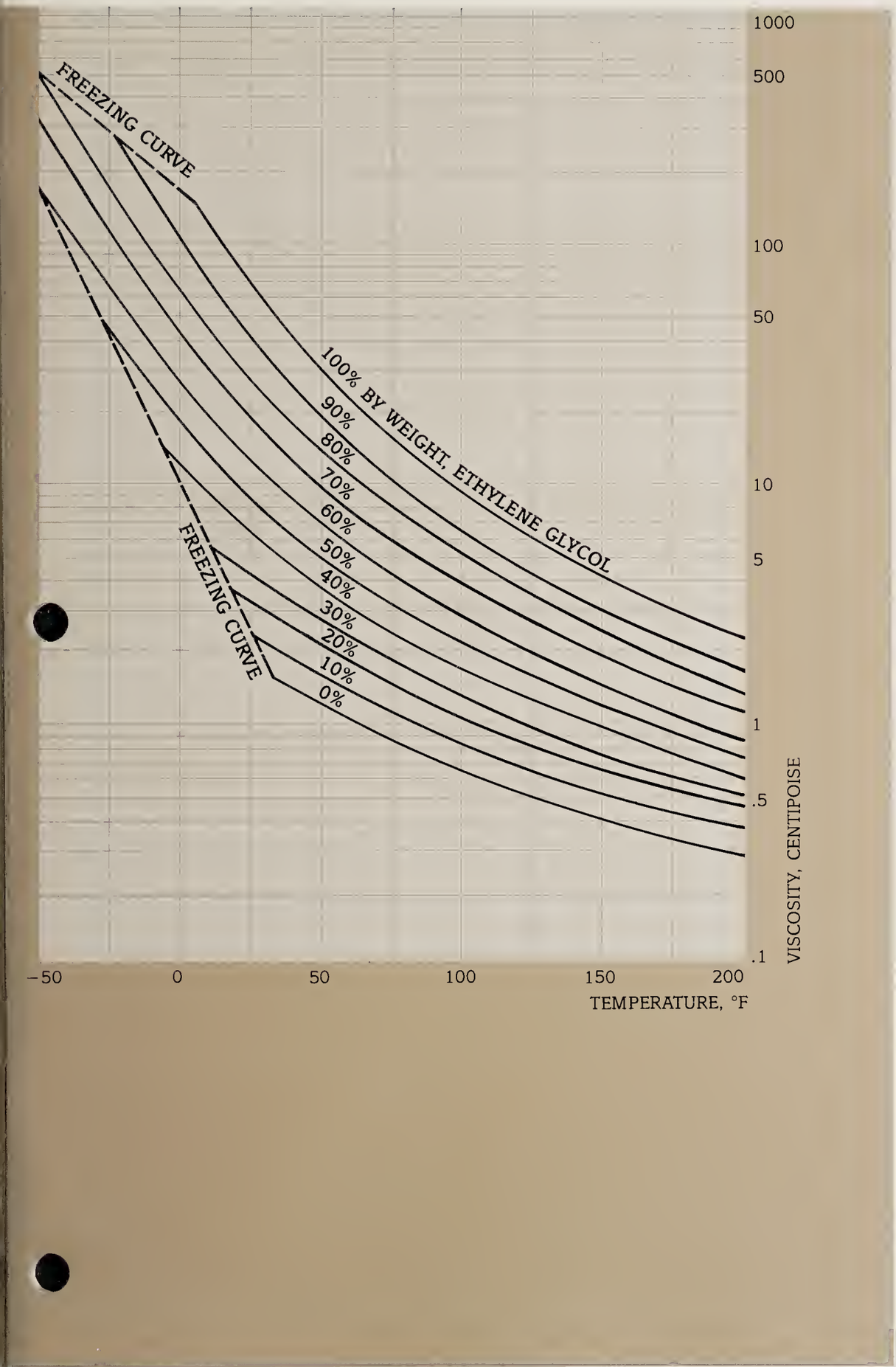
* "x" and "y" may be the same or different numbers

Viscosity Viscosity is a measure of the internal friction of a liquid. As viscosity increases, the tendency to flow decreases. Viscosities of solutions of DOWFROST and DOWTHERM SR-1 inhibited glycols vary inversely with temperature and directly with concentration. These curves are important when viscosity information is required for pumping, filtering, and piping calculations, or for calculation of heat transfer efficiency factors.

Viscosity is given in centipoise. This can easily be converted to centistokes by dividing centipoise by the density in grams per milliliter at the indicated temperature. Densities are given on pg. 16 & 17.

VISCOSITIES
OF AQUEOUS SOLUTIONS
OF DOWFROST





VISCOSITIES
OF AQUEOUS SOLUTIONS
OF DOWTHERM SR-1

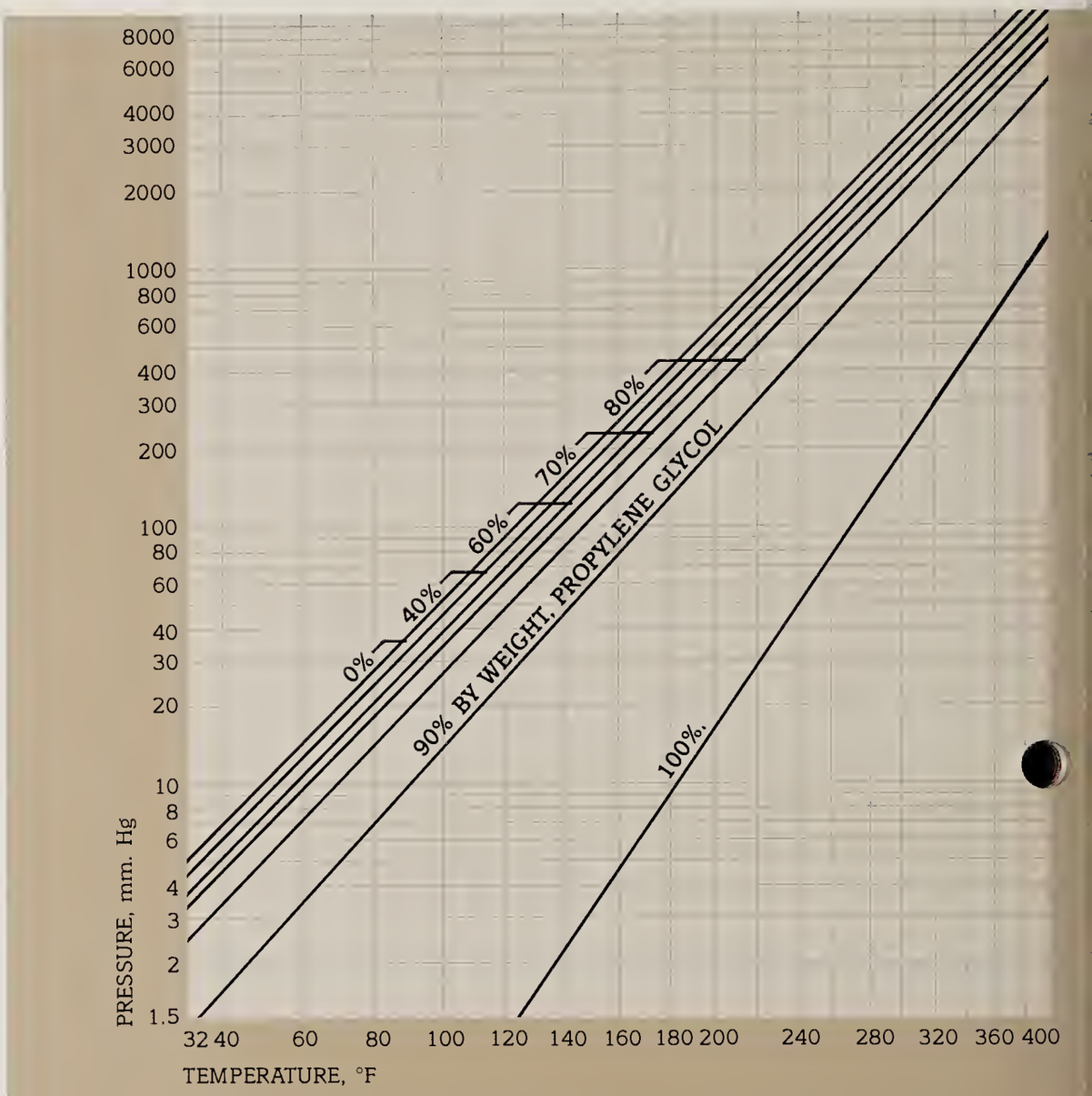
Vapor pressure and boiling point

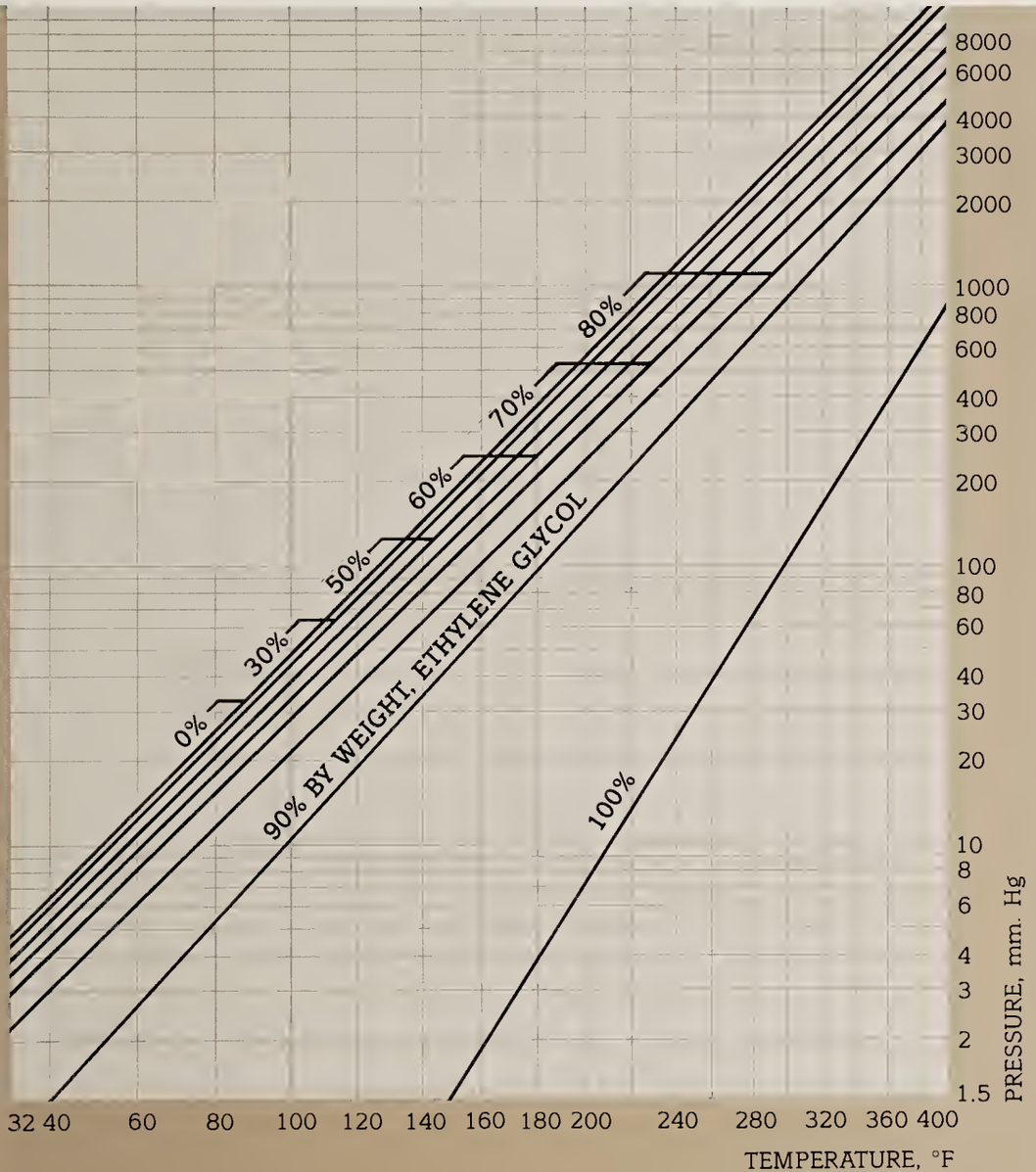
All liquids can form vapors which exert pressures. The vapor pressures exerted increase with temperature. Solutions of DOWFROST and DOWTHERM SR-1 inhibited glycols have vapor pressures lower than plain water and their boiling points are above that of water.

Solutions of DOWFROST and DOWTHERM SR-1 have vapor pressures that approach that of plain water due primarily to the water in solution. The vapor pressure of the glycol itself is much lower. As a result, solutions of DOWFROST or DOWTHERM SR-1 will tend to lose their water by evaporation as temperatures rise above the dew point. It should be noted that since glycols are hygroscopic, the fluids will pick up water from the air and become more dilute as the temperature drops below the dew point. Closed containers or processes help prevent this from becoming a problem.

In designing systems to withstand vapor pressures of solutions of DOWFROST or DOWTHERM SR-1, engineers often find it easier to use steam tables. Since these solutions have slightly lower vapor pressures than plain water, the system design would then be conservative.

TOTAL PRESSURES OVER AQUEOUS SOLUTIONS OF DOWFROST





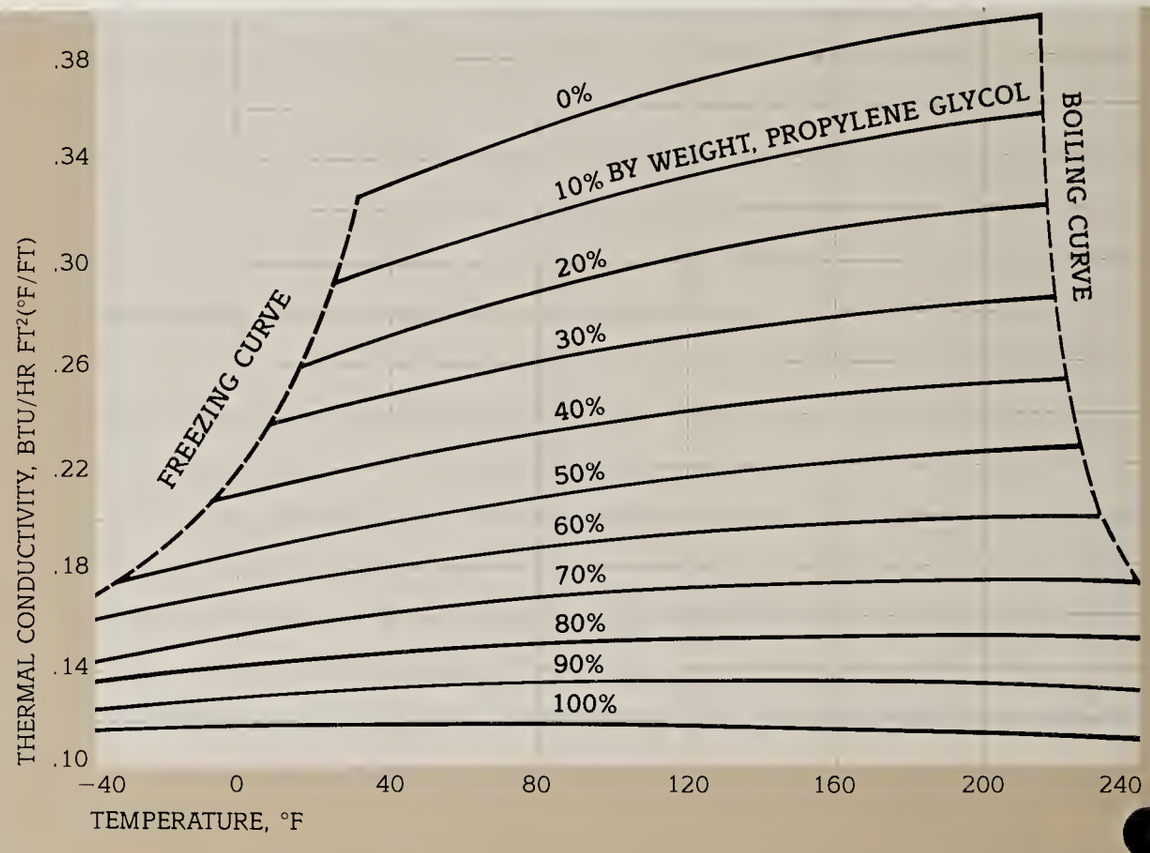
% Glycol by weight	TEMPERATURE, °F DOWFROST	DOWTHERM SR-1
10	212.5	214.0
20	213.0	216.0
30	216.0	218.0
40	219.0	222.0
50	222.0	225.0
60	225.0	230.0
70	230.0	242.0
80	245.0	255.0
90	263.0	285.0
100	370.0	387.0

BOILING POINTS
FOR AQUEOUS SOLUTIONS
OF DOWFROST
AND DOWTHERM SR-1

TOTAL PRESSURES
OVER AQUEOUS SOLUTIONS
OF DOWTHERM SR-1

Thermal conductivity is a measure of the rate with which fluid can conduct heat away from a heated surface of a given size. Plain water has the highest thermal conductivity.

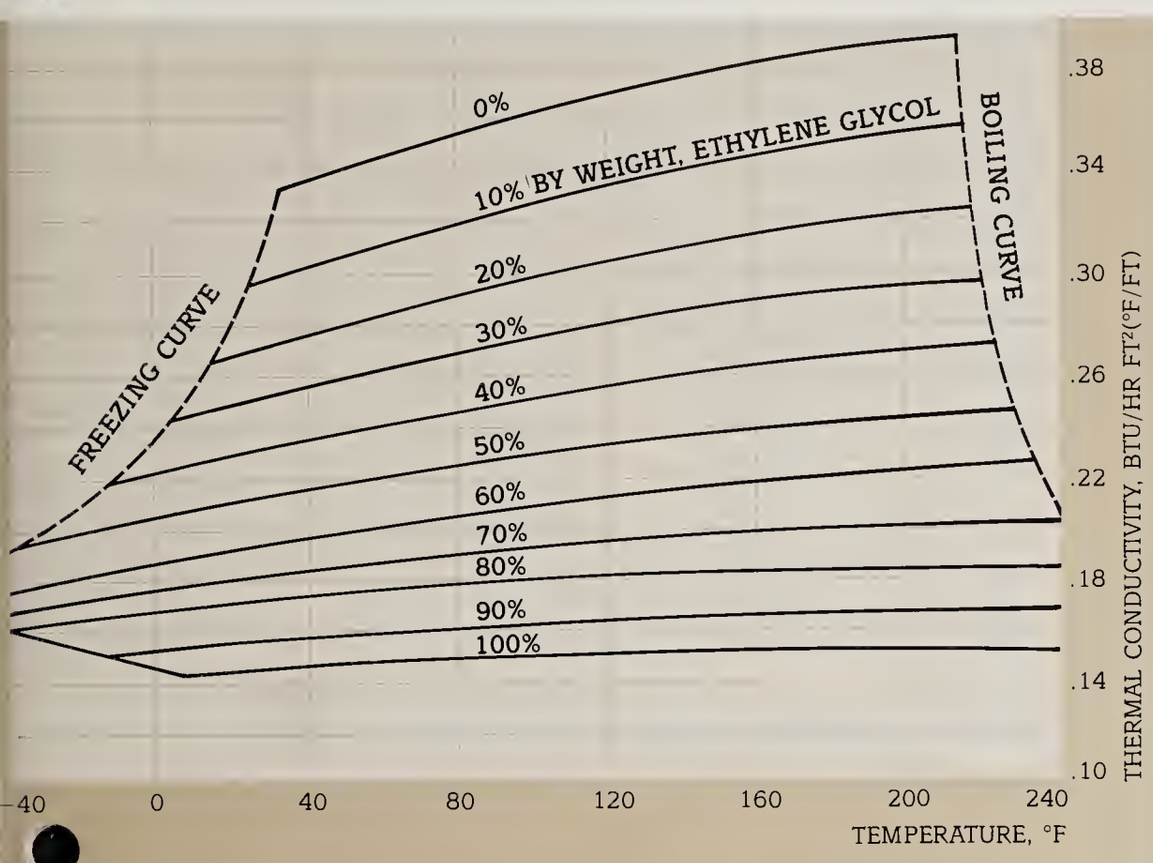
THERMAL CONDUCTIVITIES OF AQUEOUS SOLUTIONS OF DOWFROST BTU/HR FT² (°F/FT)



Specific heat is the amount of heat required to raise a unit weight of a substance one degree in temperature, expressed as BTU/LB./°F or Calories/g/°C. Specific heat of water at room temperature is approximately 1. Specific heats of glycols vary with temperature and are shown here. As expected, the more water, the higher the specific heat of a glycol solution.

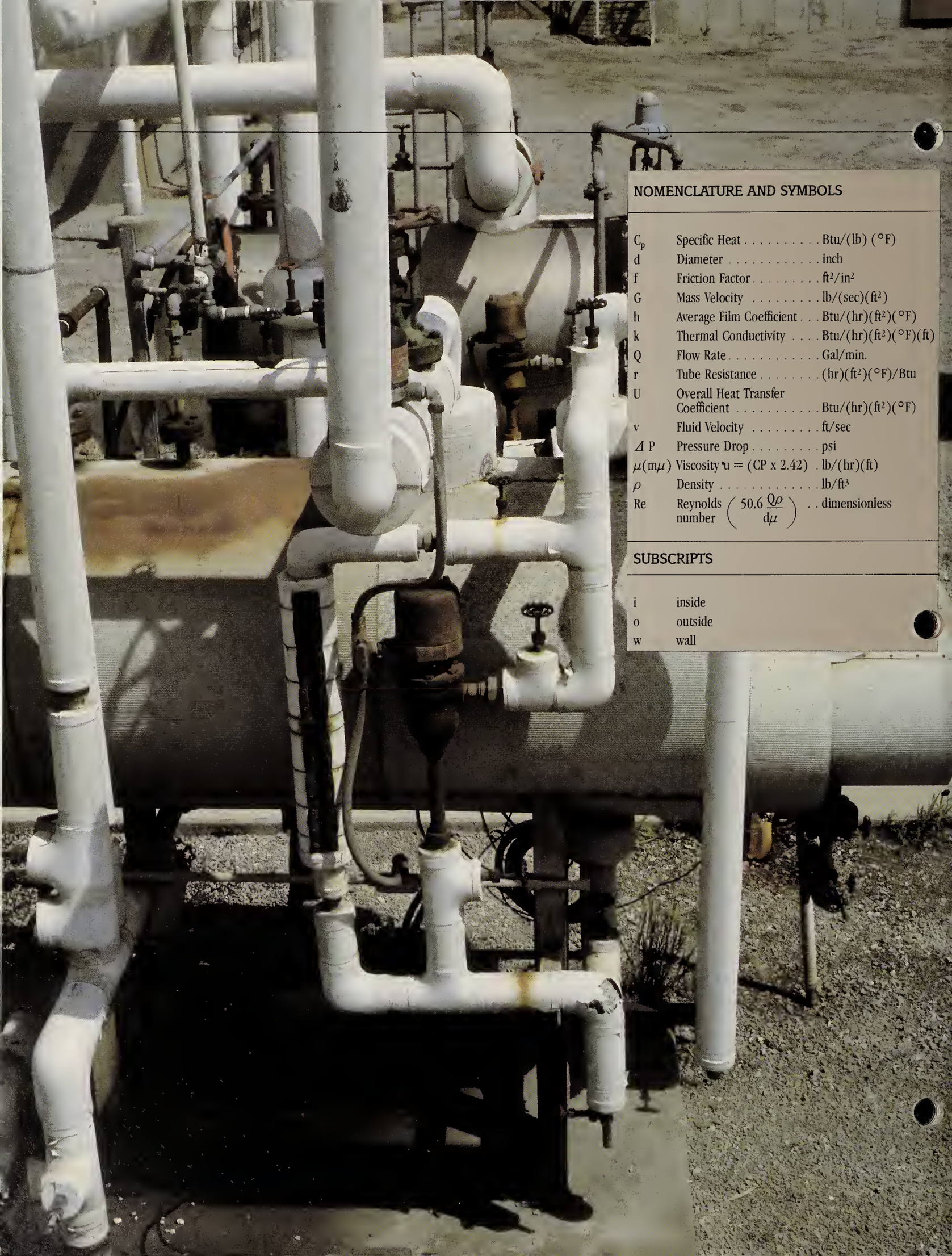
SPECIFIC HEATS OF AQUEOUS SOLUTIONS OF DOWFROST AND DOWTHERM SR-1 (BTU/LB°F)

% by weight	100%		80%		60%	
Temp. °F	Ethylene Glycol	Propylene Glycol	Ethylene Glycol	Propylene Glycol	Ethylene Glycol	Propylene Glycol
−40		.507	.598	.610	.700	.732
−20		.523	.610	.626	.712	.744
0		.539	.623	.641	.723	.757
20	.536	.555	.635	.656	.734	.700
40	.549	.571	.648	.673	.746	.782
60	.563	.587	.660	.687	.757	.795
80	.576	.603	.673	.702	.769	.808
100	.590	.619	.685	.717	.780	.821
120	.604	.635	.697	.733	.792	.833
140	.618	.651	.710	.748	.803	.846
160	.632	.667	.722	.763	.814	.857
180	.646	.683	.735	.778	.825	.871
200	.660	.699	.748	.794	.837	.882
220	.674	.715	.761	.809	.849	.895
240	.688	.731	.774	.824	.861	.907



THERMAL CONDUCTIVITIES OF AQUEOUS SOLUTIONS OF DOWTHERM SR-1 BTU/HR FT² (°F/FT)

40%		20%		10%	
Ethylene Glycol	Propylene Glycol	Ethylene Glycol	Propylene Glycol	Ethylene Glycol	Propylene Glycol
.830	.881				
.838	.887	.936	.965		
.847	.893	.938	.967	.975	.983
.855	.900	.940	.970	.976	.985
.864	.907	.942	.972	.977	.986
.872	.913	.944	.975	.978	.988
.880	.919	.946	.977	.979	.990
.888	.925	.948	.980	.980	.991
.896	.930	.950	.983	.981	.992
.905	.936	.952	.984	.982	.994
.914	.944	.954	.987	.982	.995
.922	.949	.956	.990	.983	.996
.930	.954	.958	.993	.984	.998



NOMENCLATURE AND SYMBOLS

C_p	Specific Heat	Btu/(lb) (°F)
d	Diameter	inch
f	Friction Factor	ft^2/in^2
G	Mass Velocity	lb/(sec)(ft^2)
h	Average Film Coefficient	Btu/(hr)(ft^2)(°F)
k	Thermal Conductivity	Btu/(hr)(ft^2)(°F)(ft)
Q	Flow Rate	Gal/min.
r	Tube Resistance	(hr)(ft^2)(°F)/Btu
U	Overall Heat Transfer Coefficient	Btu/(hr)(ft^2)(°F)
v	Fluid Velocity	ft/sec
Δ P	Pressure Drop	psi
μ(mμ)	Viscosity u = (CP x 2.42)	lb/(hr)(ft)
ρ	Density	lb/ft^3
Re	Reynolds number $\left(50.6\,\frac{Q\rho}{d\mu}\right)$	dimensionless

SUBSCRIPTS

i	inside
o	outside
w	wall

ENGINEERING DATA FOR DETERMINING HEAT TRANSFER

This section contains helpful information for engineers, designers, operators, and maintenance personnel who are involved in problems dealing with heat transfer. It includes facts about film coefficients and pressure drop in pipes for aqueous solutions of DOWFROST and DOWTHERM SR-1 heat transfer fluids and for water.

Heat transfer coefficients

The overall heat transfer coefficient (U) must be determined in order to evaluate the heat transfer surface required. The overall heat transfer coefficient is influenced by the fluid film heat transfer rates on each side of the tube (h_i and h_o) and the resistance through the tube wall (r_w). In terms of these individual factors, the following equation can be written:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} + r_w$$

If one film coefficient is small and the other very large, the smaller coefficient provides the major resistance to heat flow. The overall heat transfer coefficient for the equipment is then very nearly equal to the smaller or "controlling" film coefficient. In many applications where DOWFROST or DOWTHERM SR-1 heat transfer fluid is used, it is the fluid being processed that offers the major resistance to heat transfer. In such cases, the overall coefficient can be significantly increased only by increasing the film coefficient of that other fluid.

Liquid film coefficients for 30, 40 and 50% solutions of DOWFROST and DOWTHERM SR-1, and for water, are shown on pages 26 through 29. These film coefficients are based on the Sieder and Tate correlating equation:

$$\frac{h_i d_i}{k} = 31.06 \left(\frac{d_i G}{\mu}\right)^{0.8} \left(\frac{C_p \mu}{k}\right)^{0.33} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

These calculations are based on the assumption that:

$$\left(\frac{\mu}{\mu_w}\right)^{0.14} = 1$$

This correlation holds only for turbulent flow and should not be used for Reynolds numbers less than 5000.

Pressure drop

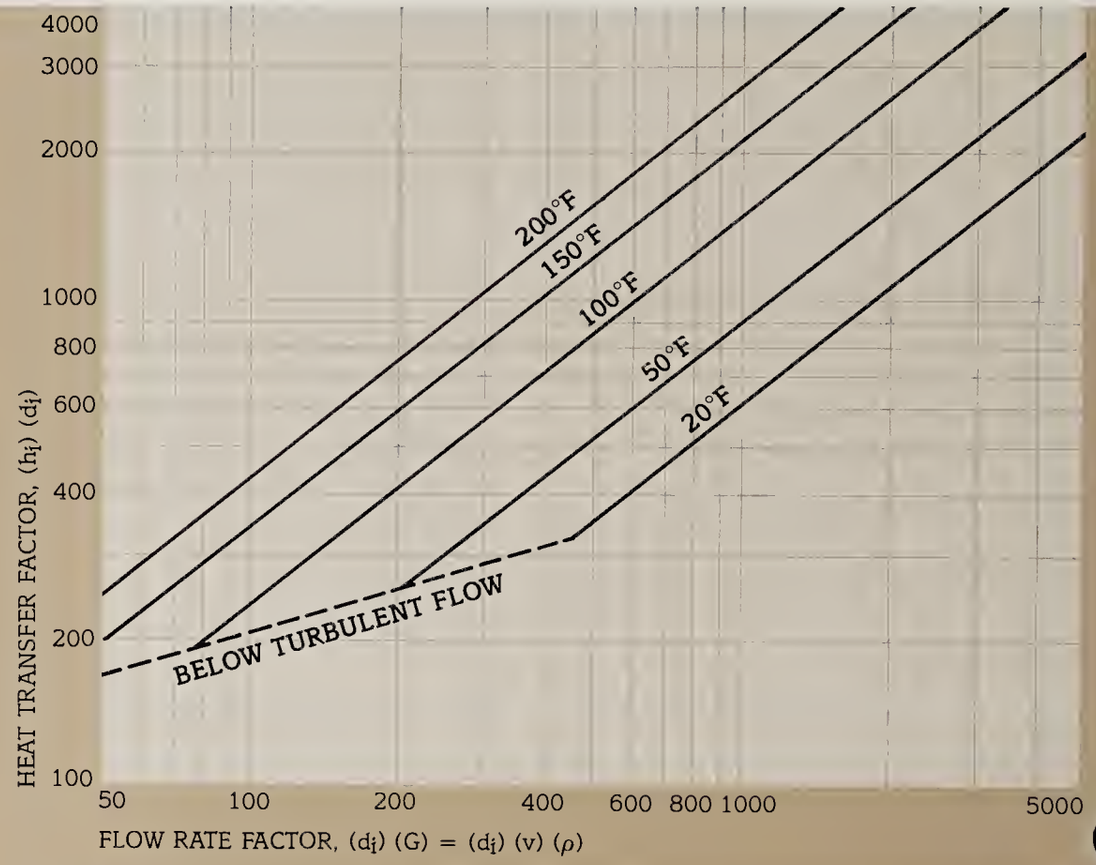
When a fluid flows over either a stationary or a moving surface, the pressure of the fluid decreases along the surface due to friction. This is called the pressure drop of the system. The Darcy equation for pressure drop of fluids in turbulent flow is:

$$\Delta P_{100} = 0.1294 \frac{f\rho v^2}{d} = 0.0216 \frac{f\rho Q^2}{d^5}$$

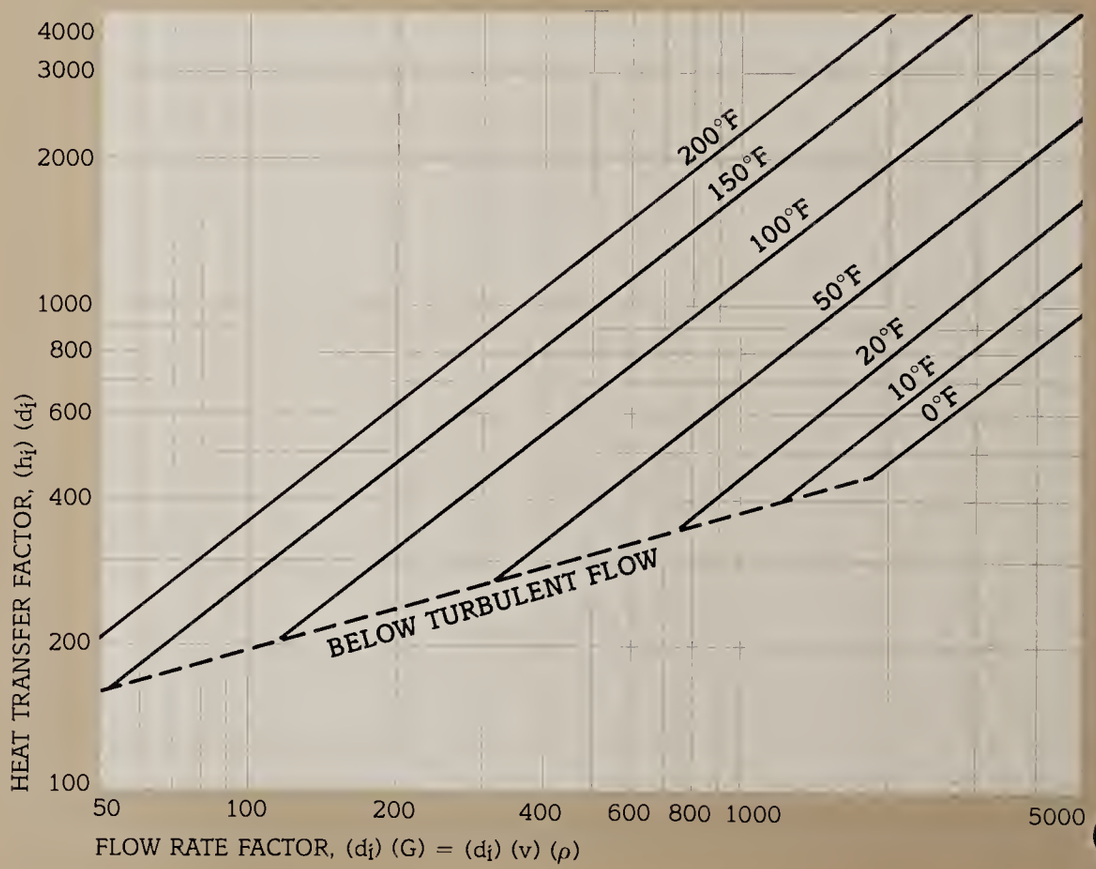
Values of f may be obtained from f versus Reynolds number plots given in standard texts.

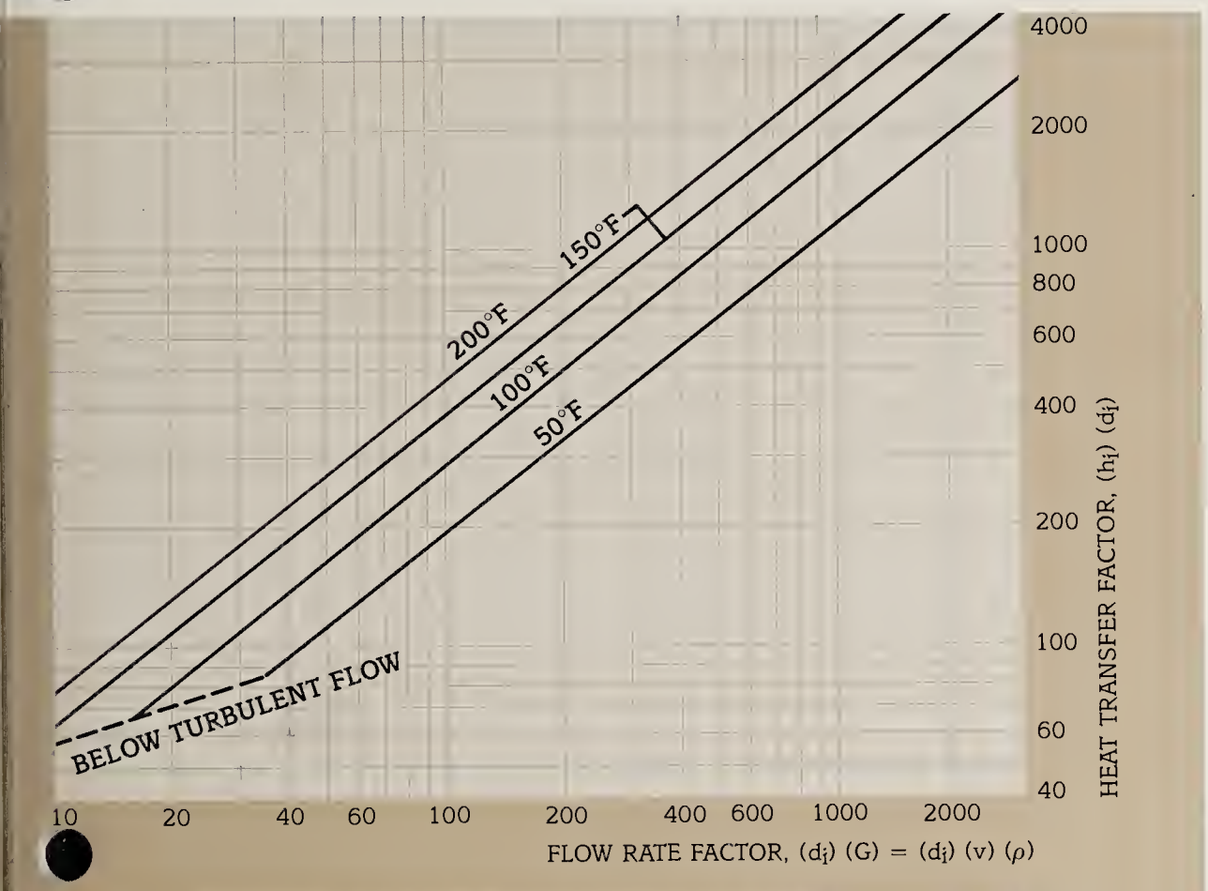
Pressure drops for 30, 40 and 50% solutions of DOWFROST and DOWTHERM SR-1, and for water flowing in pipes are shown on pages 30 through 33.

LIQUID FILM COEFFICIENTS FOR 30% VOLUME DOWFROST INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)

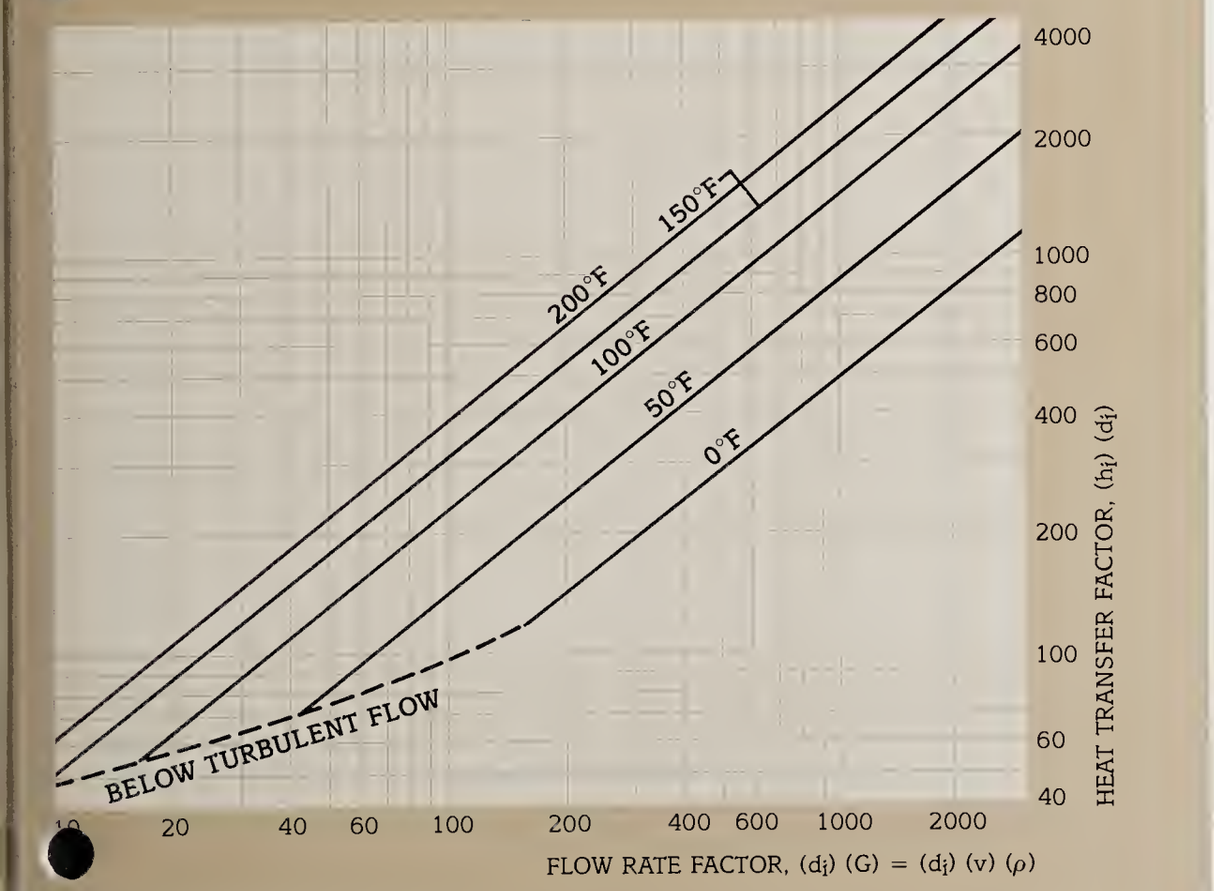


LIQUID FILM COEFFICIENTS FOR 40% VOLUME DOWFROST INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)



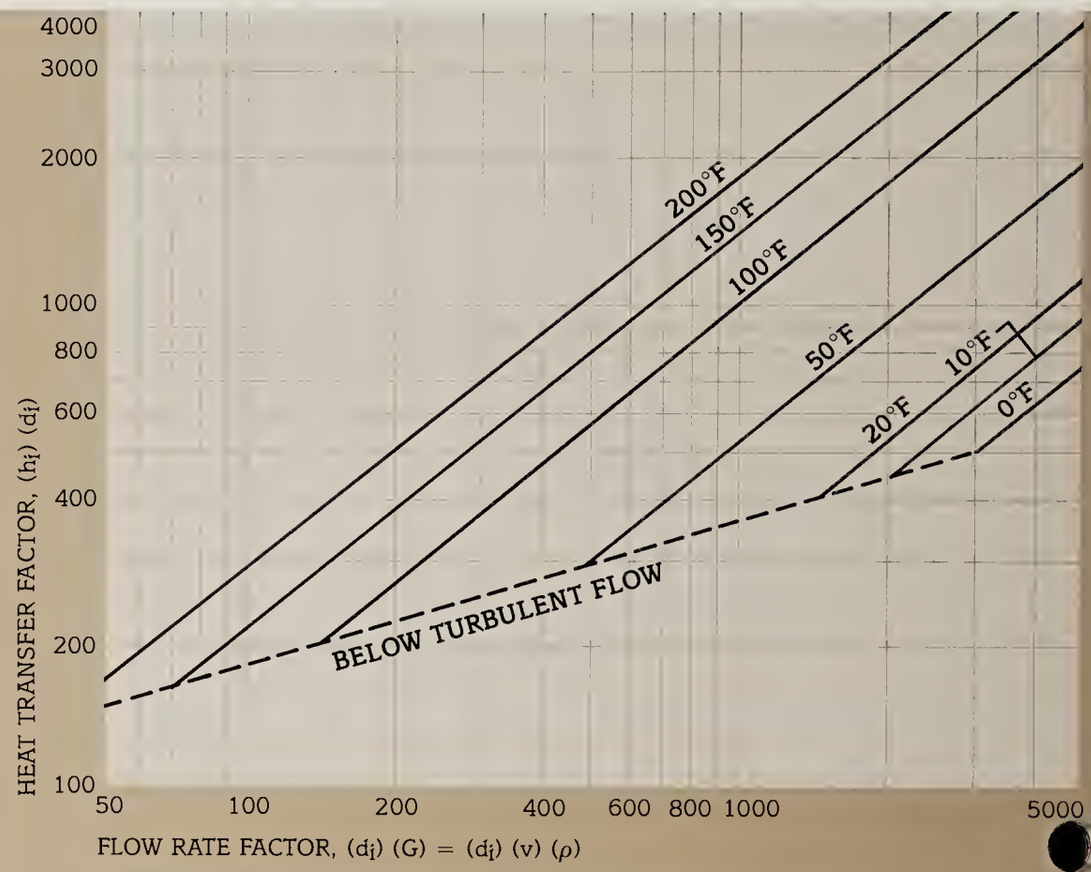


LIQUID FILM COEFFICIENTS FOR 30% VOLUME DOWTHERM SR-1 INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)

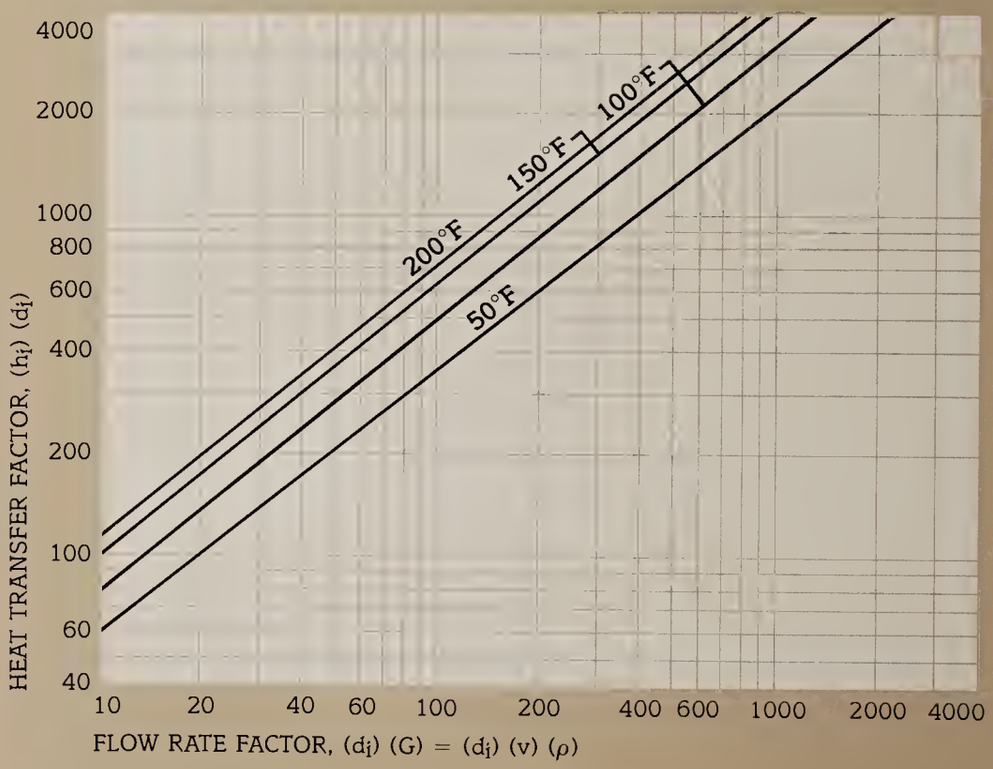


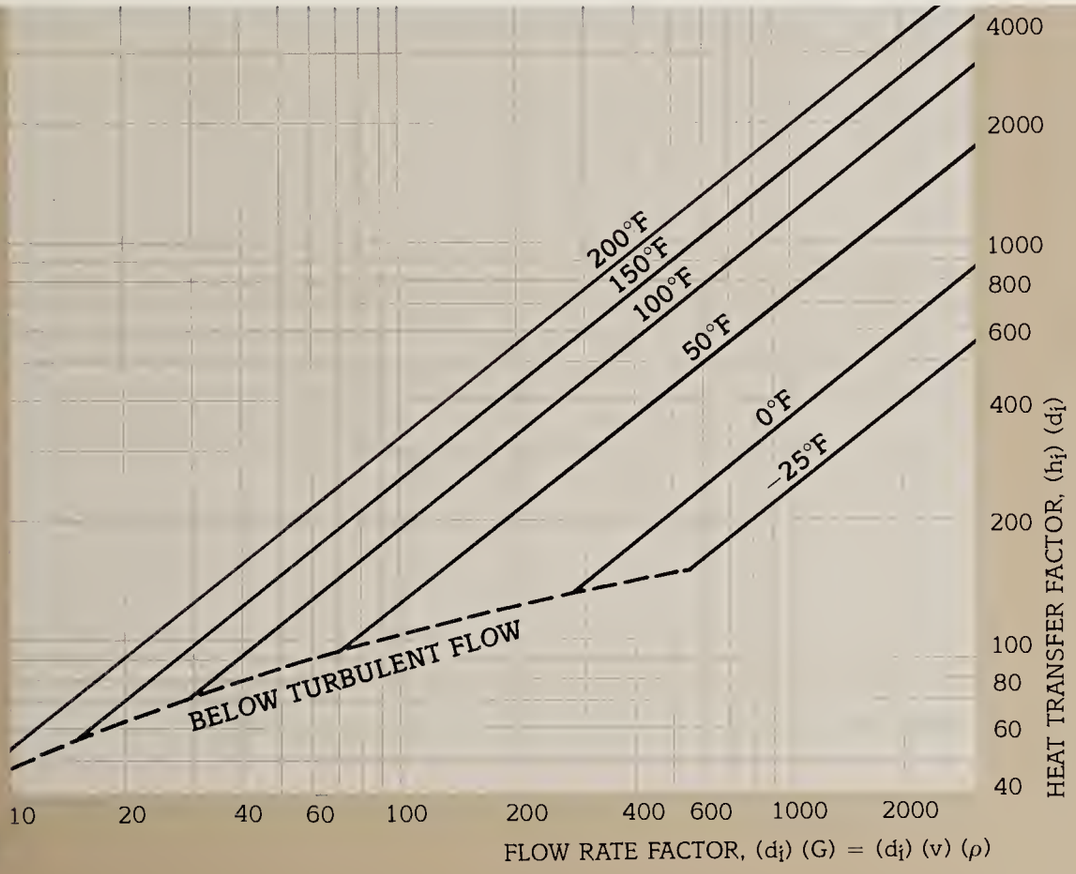
LIQUID FILM COEFFICIENTS FOR 40% VOLUME DOWTHERM SR-1 INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)

LIQUID FILM COEFFICIENTS FOR 50% VOLUME DOWFROST INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)



LIQUID FILM COEFFICIENTS FOR WATER INSIDE PIPES & TUBES (TURBULENT FLOW ONLY)

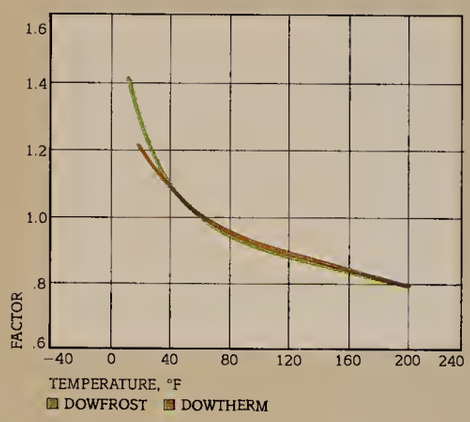


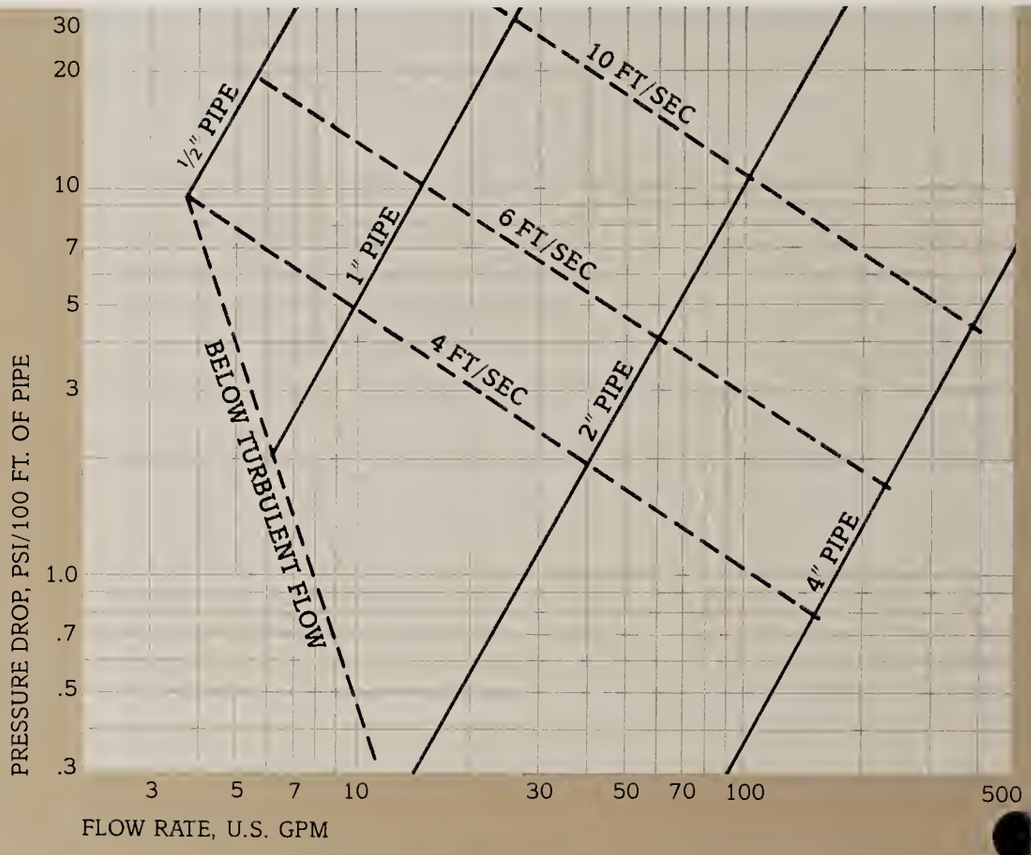


LIQUID FILM COEFFICIENTS FOR 50% VOLUME DOWTHERM SR-1 INSIDE PIPES AND TUBES (TURBULENT FLOW ONLY)

PRESSURE DROP VS. FLOW RATE OF 30% VOLUME DOWFROST IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

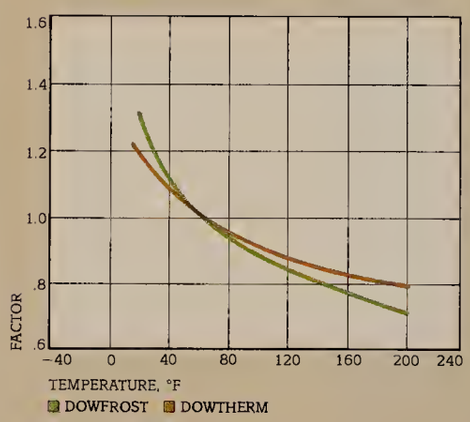
TEMPERATURE CORRECTION MULTIPLIER FACTOR, 30% SOL.

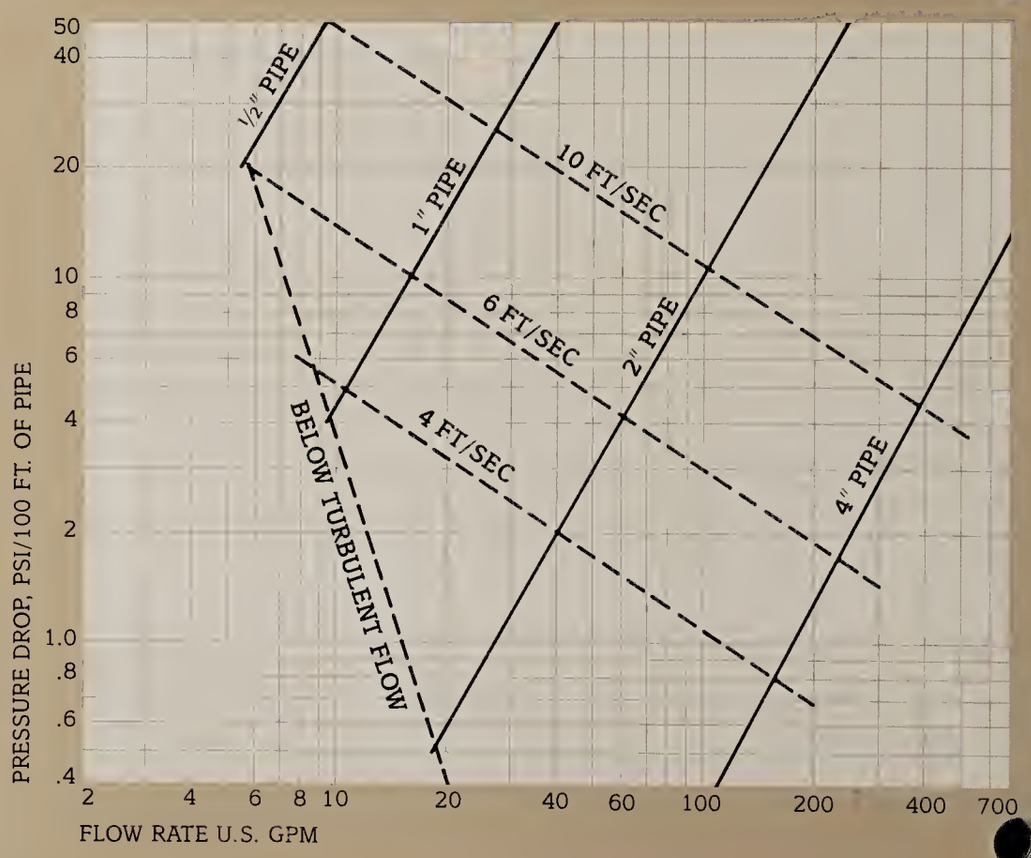


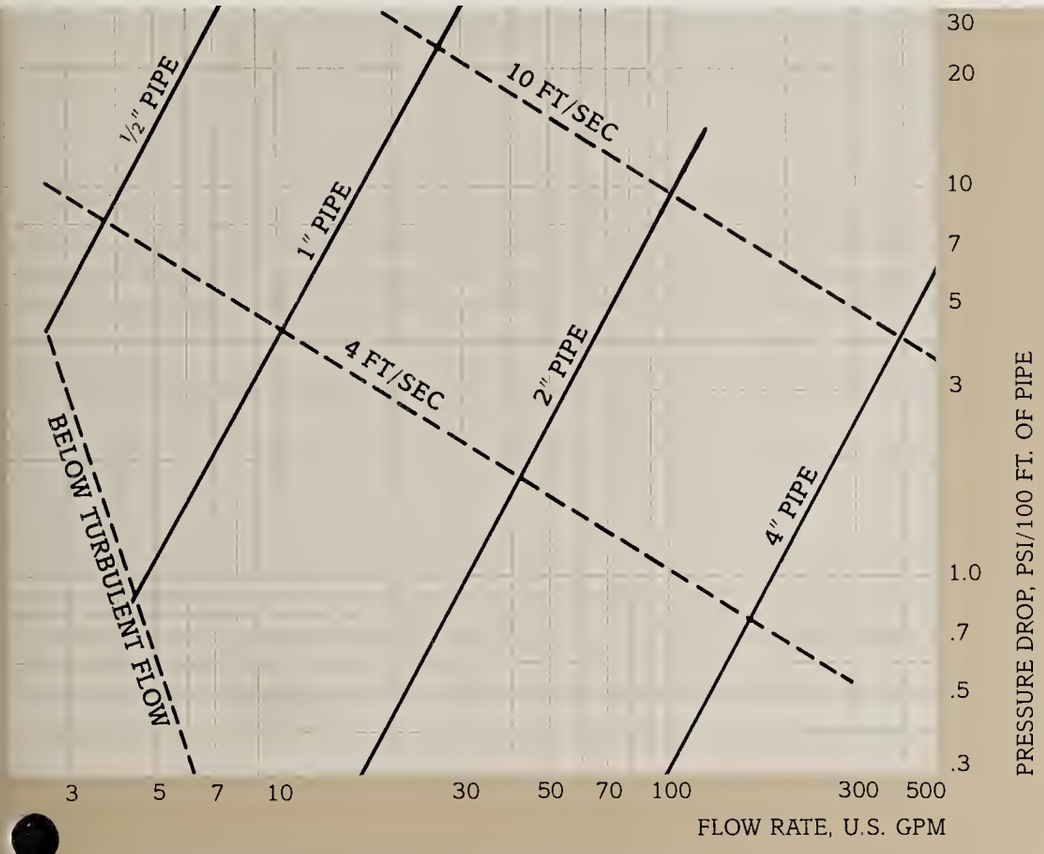


PRESSURE DROP VS. FLOW RATE OF 40% VOLUME DOWFROST IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

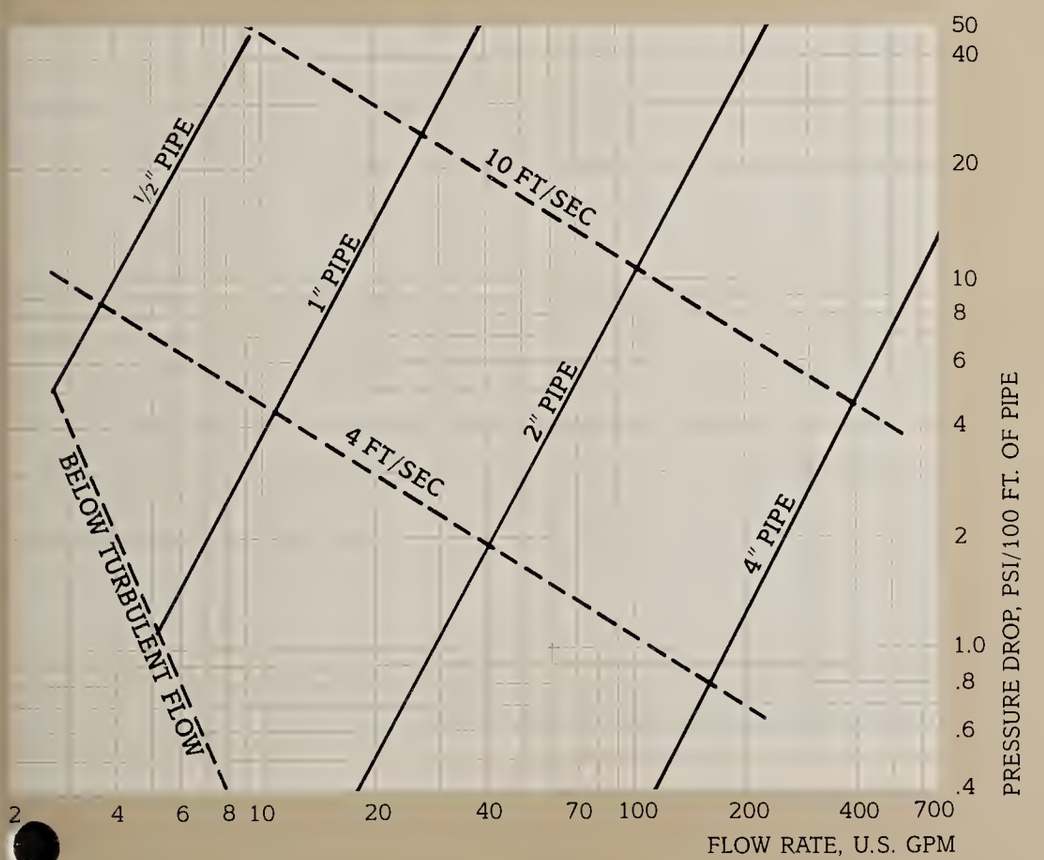
TEMPERATURE CORRECTION MULTIPLIER FACTOR, 40% SOL.







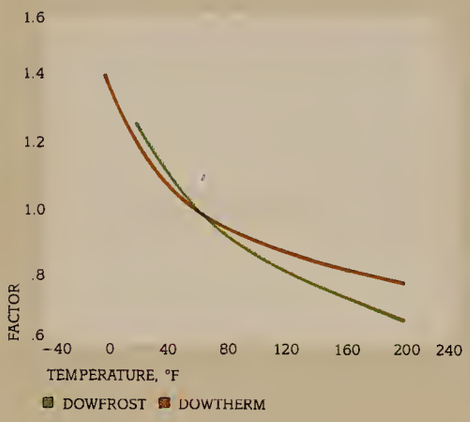
PRESSURE DROP VS. FLOW RATE OF 30% VOLUME DOWTHERM SR-1 IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

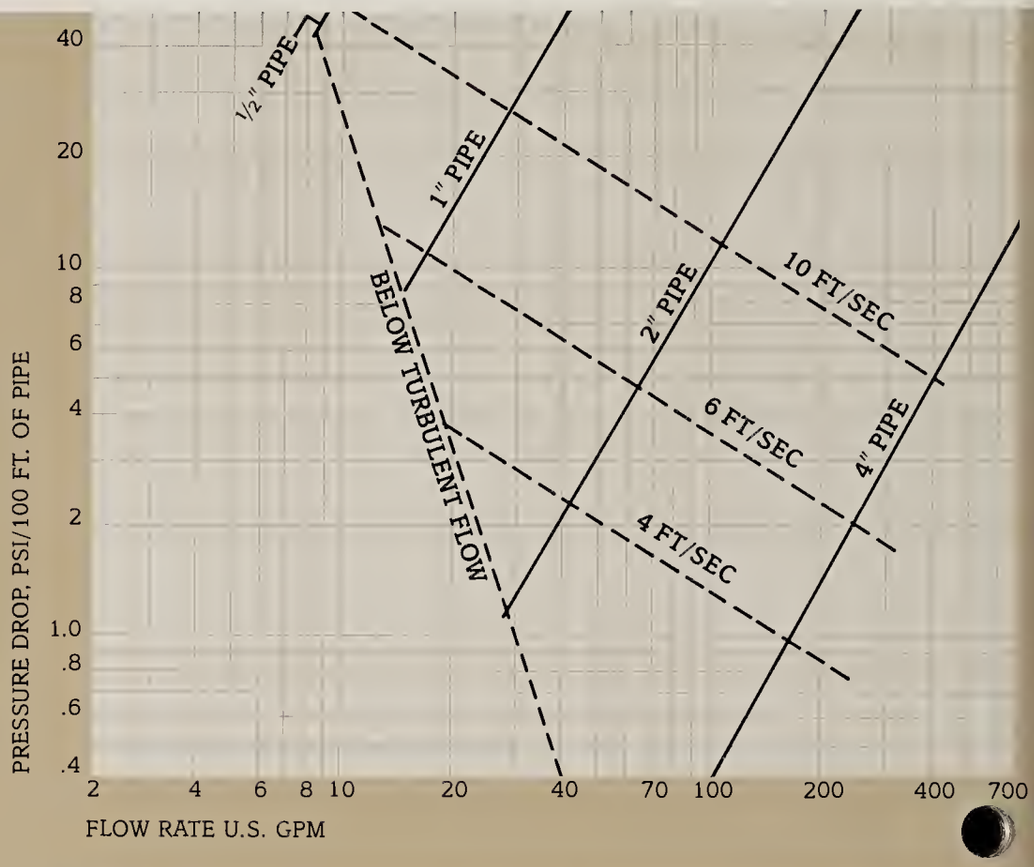


PRESSURE DROP VS. FLOW RATE OF 40% VOLUME DOWTHERM SR-1 IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

PRESSURE DROP VS. FLOW RATE OF 50% VOLUME DOWFROST IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

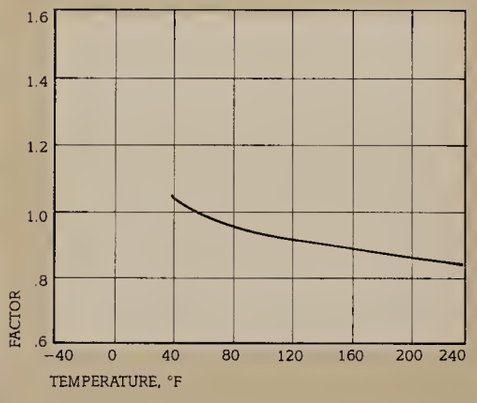
TEMPERATURE CORRECTION MULTIPLIER FACTOR, 50% SOL.

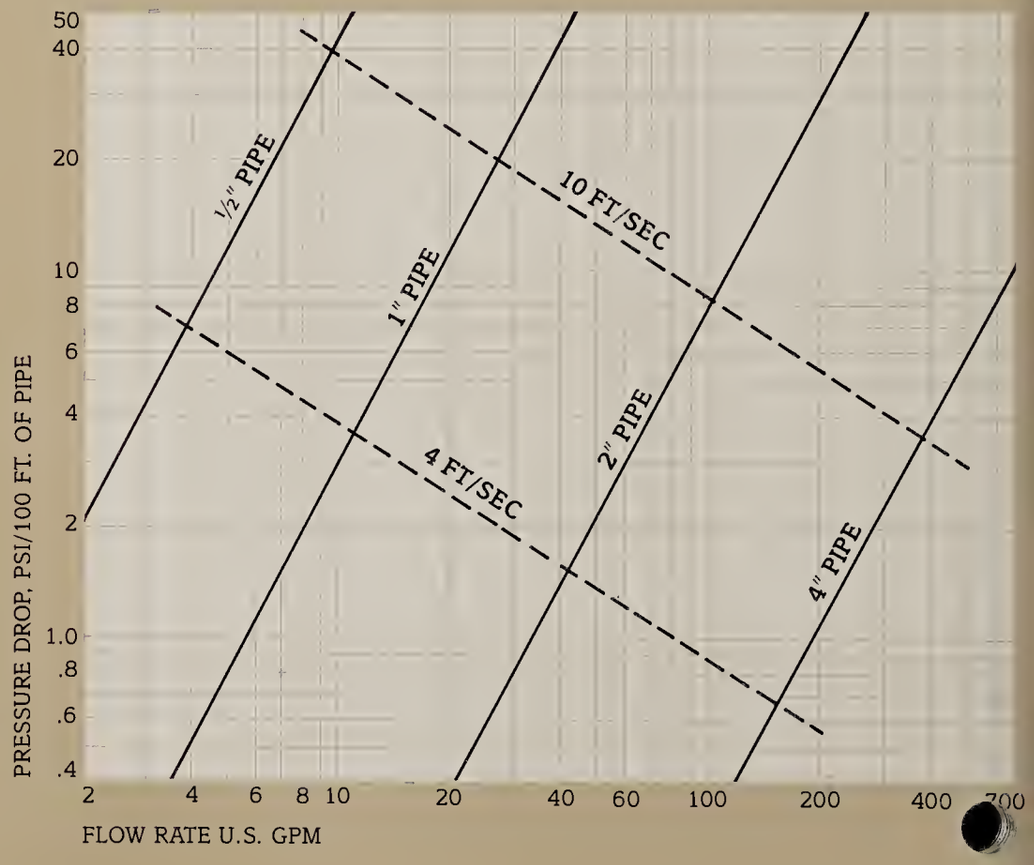


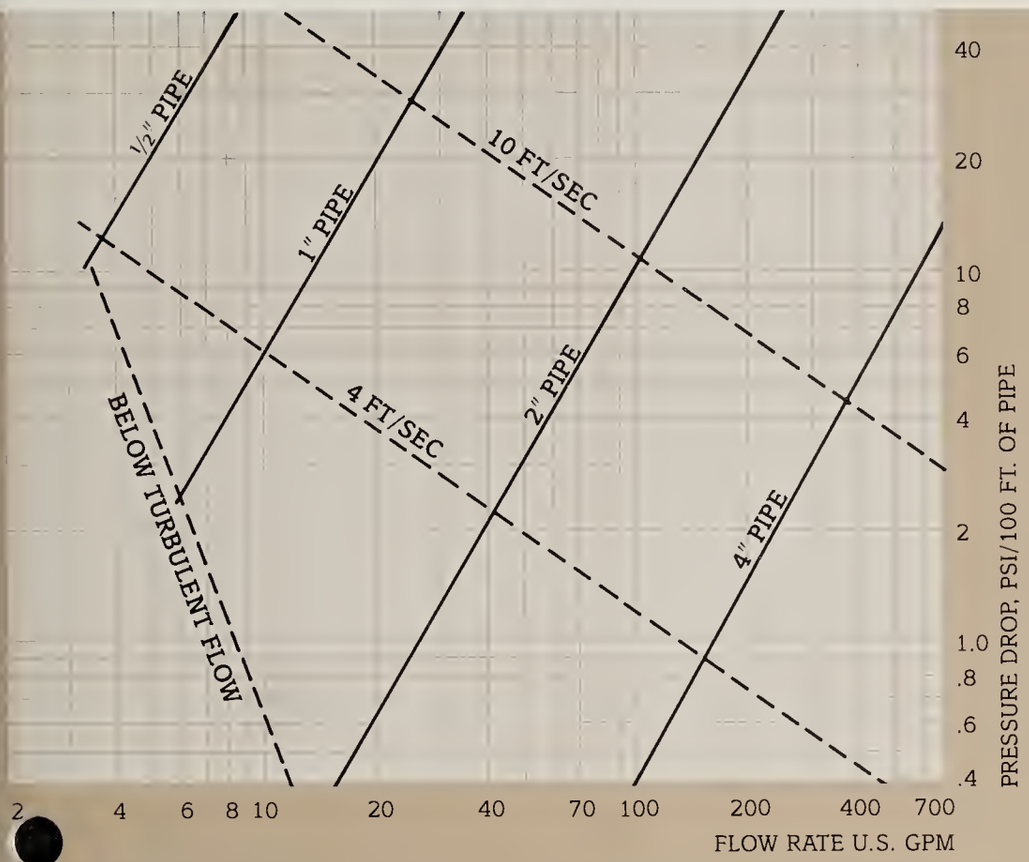


PRESSURE DROP VS. FLOW RATE OF WATER IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

TEMPERATURE CORRECTION MULTIPLIER FACTOR, WATER







PRESSURE DROP VS. FLOW RATE OF 50% VOLUME DOWTHERM SR-1 IN SCHEDULE 40 PIPE (TURBULENT FLOW ONLY)

TEMPERATURE CONVERSION

°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
−40	−40.00	+20	−6.67	+52	+11.11	+84	+28.89	+170	+76.67
−30	−34.44	+22	−5.56	+54	+12.22	+86	+30.00	+180	+82.22
−20	−28.89	+24	−4.44	+56	+13.33	+88	+31.11	+190	+87.78
−15	−26.12	+26	−3.33	+58	+14.44	+90	+32.22	+200	+93.33
−10	−23.33	+28	−2.22	+60	+15.56	+92	+33.33	+210	+98.89
−5	−20.56	+30	−1.11	+62	+16.67	+94	+34.44	+220	+104.44
0	−17.78	+32	+0.00	+64	+17.78	+96	+35.56	+240	+115.56
+2	−16.67	+34	+1.11	+66	+18.89	+98	+36.67	+260	+126.67
+4	−15.56	+36	+2.22	+68	+20.00	+100	+37.78	+280	+137.78
+6	−14.44	+38	+3.33	+70	+21.11	+110	+43.33	+300	+148.89
+8	−13.33	+40	+4.44	+72	+22.22	+120	+48.89	+320	+160.00
+10	−12.22	+42	+5.56	+74	+23.33	+130	+54.44	+340	+171.11
+12	−11.11	+44	+6.67	+76	+24.44	+140	+60.00	+360	+182.22
+14	−10.00	+46	+7.78	+78	+25.56	+150	+65.56	+380	+193.33
+16	−8.89	+48	+8.89	+80	+26.67	+160	+71.11	+400	+204.44
+18	−7.78	+50	+10.00	+82	+27.78				

$$°F = (1.8 \times °C) + 32 \qquad °C = \frac{(°F - 32)}{1.8}$$

TOXICOLOGICAL INFORMATION AND CORROSION CHARACTERISTICS OF DOWFROST & DOWTHERM SR-1 HEAT TRANSFER FLUIDS

Toxicology of DOWFROST

Propylene glycol, the major component in DOWFROST, is extremely low in acute oral toxicity. The single dose LD_{50} values for rats, rabbits and dogs have been found to be greater than or equal to 20 grams per kilogram of body weight. As much as one-fourth to one-half of propylene glycol ingested by humans appears unchanged in the urine in 24 hours.

Chronic oral toxicity is also very low. Rats receiving drinking water containing up to 10% of propylene glycol over a period of 140 days develop no ill effects as reflected by growth or kidney effects. Rats receiving 4.9% in their diet for 24 months were normal in their growth. They did sustain very slight liver, but no kidney, injury.[1]

Propylene glycol causes no serious skin irritation. Very severe prolonged exposure may, however, produce slight irritation or softening of the skin comparable to that caused by glycerine under similar conditions. There is no evidence that propylene glycol is absorbed through the skin in significant amounts and it is not expected to cause irritation when in contact with the eyes. Inhalation of atmospheres containing propylene glycol present no hazard to health due to its low toxicity and low vapor pressure.

DOWFROST heat transfer fluid, containing dipotassium phosphate, presents no more hazard than pure propylene glycol. The dipotassium phosphate used in DOWFROST is food grade material.

Toxicology of DOWTHERM SR-1

DOWTHERM SR-1 heat transfer fluid has a moderate acute oral toxicity for humans, but should present no significant problem from ingestion incidental to industrial handling or general use.

The single oral dose of ethylene glycol, the primary component of DOWTHERM SR-1, lethal for humans, has been estimated at 1.56 g/kg or about 100 ml. (111 g) per person. The undiluted material, other than causing slight pain, is essentially non-irritating to the eyes.

Special precautions should be unnecessary for industrial handling although direct contact of the liquid with food products should be avoided.

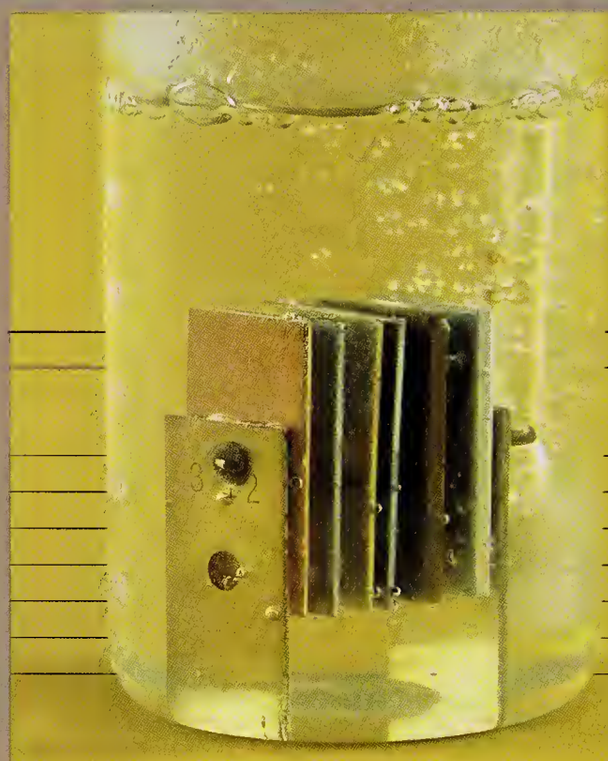
Undiluted DOWTHERM SR-1 heat transfer fluid is essentially harmless to exposed skin and is not likely to be absorbed through skin in toxic amounts. It may be slightly irritating, if confined to the skin, comparable to the irritation caused by glycerine under similar conditions. Generally speaking, ordinary care and cleanliness should be adequate to avoid skin irritation.

Inhalation of vapors or mists from hot solutions of ethylene glycol could cause throat or eye irritation and should be avoided.

The inhibitor for DOWTHERM SR-1 heat transfer fluid has low oral toxicity and should present no problem from ingestion incidental to industrial handling and use. Skin contact with this inhibitor should not cause significant irritation. Prolonged skin exposure may result in moderate irritation. The inhibitor for DOWTHERM SR-1 is not likely to be absorbed through the skin in toxic amounts. Reasonable care and personal cleanliness should be adequate to avoid skin difficulties.

Care to avoid eye contact is, of course, recommended. Eye contact may cause pain and slight transient irritation, but no corneal injury is likely.

[1] "Industrial Hygiene and Toxicology", Frank A. Patty, Editor, 1981. Interscience Publishers.



CORROSION RATE* (mils penetration per year)

Metal	Plain Water	Uninhibited Propylene Glycol	DOWFROST	Uninhibited Ethylene Glycol	DOWTHERM SR-1
Copper	0.08 mpy	0.16 mpy	0.20 mpy	0.16 mpy	0.12 mpy
Solder	3.14	34.7	0.03	56.5	0.14
Brass	0.22	0.20	0.16	0.46	0.11
Steel	9.69	9.8	0.04	44.5	0.03
Cast Iron	21.2	16.2	0.15	55.7	0.13
Aluminum	13.2	1.8	0.26	19.8	0.44

NOTE: The test data information is recommended for screening purposes only.

*Based on Corrosion Test ASTM D1384; 190°F - 2 weeks; Standard ASTM Test Metals 30% Glycol in Deionized Water, Air Bubbling

Corrosion characteristics

There are two ways in which the inhibitors in DOWFROST and DOWTHERM SR-1 fluids provide corrosion protection for most common metals found in food processing and heat transfer equipment. First, they passivate the surface of the metals. The second function of these inhibitors is to buffer any acids that may be formed as the glycols oxidize. Such acids, if left in solution, would lower the pH and contribute to corrosion. The amount of buffering capacity and related corrosion protection relates directly to the amount of inhibitor in solution. The standard ASTM D 1384 corrosion test is a screening test which measures the relative passivity protection provided by different solutions on standard metals under standard test conditions.

The data above shows relative corrosion rates in ASTM D 1384 for DOWFROST and DOWTHERM SR-1, compared to uninhibited glycols and plain water. Under the conditions of the test, the solutions of DOWFROST and DOWTHERM SR-1 fall well within what would be considered adequate for this screening test. Rates in excess of 0.5 mpy (2.5 mpy for aluminum) would generally not be considered adequate for corrosion protection.

However, it should be noted that the presence of excessive amounts (> 50 ppm) of contaminants such as chloride, sulfate, or ammonia could contribute to system corrosion not evident in tests such as those reported above where dilution water was deionized.

This data also illustrates how uninhibited glycols and plain water can become corrosive relative to DOWFROST and DOWTHERM SR-1.

HANDLING, STORAGE, AND DISPOSAL CONSIDERATIONS FOR DOWFROST AND DOWTHERM SR-1

Storage of DOWFROST and DOWTHERM SR-1 heat transfer fluids presents no unusual problems. The materials do not readily solidify; are relatively low in toxicity; have high flash points; and can be handled without posing a hazard to health. As a precaution, however, sparks or flames should be avoided during transfer or processing operations because undiluted glycols can be ignited. Tank truck shipments can be emptied into storage tanks or clean drums.

Tank storage

Ordinary steel tanks are normally satisfactory storage for DOWFROST or DOWTHERM SR-1. However, during extended storage, slight discoloration may occur from iron contamination. Rusting in the vapor space where there is no inhibitor occurs when condensate collects on the walls and oxygen is present. This problem can be minimized by closing any vent to the tank to limit oxygen intake. To eliminate the possibility of iron contamination, stainless steel, aluminum, or ordinary steel lined with vinyl phenolic, epoxy resins can be used on tank construction.

Insulation and heat are required for storage of DOWFROST or DOWTHERM SR-1 at low temperatures. This will prevent freezing or pumping problems due to high viscosity. Maintaining temperatures above 35°F is usually sufficient to avoid such difficulty.

Drum storage

DOWFROST and DOWTHERM SR-1 heat transfer fluids may be stored in drums in which shipments are made. Because glycols are hygroscopic, it is important that the drum cap be replaced tightly after each withdrawal to keep the material in the drum from absorbing water. Drums should be stored inside a heated building during the cold months. This will ensure the glycol is in liquid form when needed.

Environmental considerations

The bio-oxygen demand for ethylene and propylene glycols approaches theoretical value in the standard 20-day test period. These materials, therefore, are readily biodegradable and should not concentrate in common water systems. The possibility of major spills in lakes or rivers, however, should be avoided, since rapid oxygen depletion may have harmful effects on aquatic organisms.

Spill, leak, and disposal procedures

Using appropriate safety equipment, small spills may be soaked up using common absorbent material. For large spills, the fluid should be pumped into suitable containers located in diked areas. The residual should be cleaned up with water. The concentrate can be handled according to local, state and federal regulations.

Salvage: Some distributors of DOWFROST and DOWTHERM SR-1 are equipped to reclaim and/or dispose of spent or contaminated fluids. Occasionally, where regulations permit, diluted spent fluids that are not otherwise contaminated can be disposed of in local sewage treatment facilities, provided those facilities are advised and prepared for such disposal in advance. Aerobic bacteria easily oxidize the fluids to carbon dioxide and water within the usual 20-day test period. The Dow Chemical Company does not normally provide a disposal or reprocessing service for spent or contaminated glycol-based fluids.

YORK

PREPARING SYSTEMS FOR THE ADDITION OF DOWFROST OR DOWTHERM SR-1 HEAT TRANSFER FLUID

In existing systems, all lines and materials should be cleaned and flushed thoroughly before charging, particularly if the old liquid is incompatible with the new inhibited glycol. A Dow technical service representative can assist you in determining compatibility of the old liquid with DOWFROST or DOWTHERM SR-1. It is important that all rust, scale, and sediment be removed. All traces of chloride should also be removed from the system, whether it is from old brine or from acid cleaner, because chlorides can contribute to corrosion. For large systems, or systems with corrosion present, consult a professional industrial cleaning organization, such as Dowell Industrial Service. If chemical cleaning is used, it is important that all traces of the cleaning agent be removed, and the system be thoroughly flushed with water.

New systems typically are coated with oil, grease, or a protective film during fabrication, storage, or construction. Dirt, solder flux, welding and pipe scale can also be a problem. Therefore, a thorough cleaning is recommended. Solutions of 1-2% sodium orthosilicate, sodium metasilicate, or trisodium phosphate can be used with water for flushing the system. System volume can be calculated during this stage either by metering in the initial fill of the system, or by chemical analysis of cleaning chemicals after known quantities are introduced into the system.

Solution make-up

Good quality water must be used for fluid makeup, with particular attention given to low levels ($<$ 50 ppm) of chloride (Cl^-), sulfate ($SO_4^{=}$), and hard water ions. Therefore distilled water, deionized water, or boiler condensate should be used. If good quality water is unavailable, pre-diluted solutions of DOWFROST and DOWTHERM SR-1 are available by special order in bulk shipments.

Automatic water make-up systems should be avoided in order to prevent undetected dilution of glycol and consequent loss of protection. Also, any flush water remaining in the system after draining should be accounted for. It is not unusual for hang-up in an industrial system to reach up to 20% of the total system volume, although 10% is more common.

Determining the initial quantity of DOWFROST or DOWTHERM SR-1 needed for freeze- or burst-protection or for low temperature operations

Concentration of DOWFROST or DOWTHERM SR-1 heat transfer fluid needed in a system depends on the kind of protection you want in winter or the temperature at which you wish to operate if the system involves refrigeration. "Freeze-protection" is required in refrigeration systems or if frigid fluid needs to be pumped. "Burst-protection" is adequate if at any time the system will remain dormant during below-freezing temperatures ($<$ 32°F), frigid fluid will not be pumped, and slushy conditions can be tolerated.

For freeze-protection, the solution must maintain a freeze point several degrees below the lowest anticipated ambient temperature. Freeze point is defined as the point at which the first ice crystals form. The quantity of inhibited glycol to be added for freeze-protection can be determined by referring to the table on page 9. The concentration selected should have a freeze point of at least 5°F below the lowest anticipated temperature.

For burst-protection, a 30% solution of DOWFROST or DOWTHERM SR-1 and water is usually adequate. This is based on Dow research and a number of recommendations from equipment manufacturers. However, because system designs vary, you'll want to discuss this subject with the manufacturer of your system.

Introducing DOWFROST or DOWTHERM SR-1 into your system

In most cases, solutions containing DOWFROST or DOWTHERM SR-1 heat transfer fluid are mixed on a volume basis. If you want to mix by weight percent, the table on page 16 gives you the volume-to-weight percent conversion. Here's the mixing procedure.

1. Calculate the quantity of DOWFROST or DOWTHERM SR-1 needed to achieve the desired results.

2. Introduce a sufficient quantity of water to check the system for tightness. Pressure testing

the system (at about twice the head pressure of the pump) at this stage can be helpful. Often pressure testing can be accomplished during the initial cleaning or flushing of the system.

3. Drain enough water from the system to provide space for the inhibited glycol quantity as calculated in Step 1.

4. Add the correct amount of DOWFROST or DOWTHERM SR-1 and any water needed to completely refill the system, allowing for liquid expansion as needed.

5. Circulate for at least 24 hours to ensure complete mixing. Check the liquid concentration with a refractometer or other method to assure the correct mixture is obtained.

MAINTAINING YOUR FLUID AND SYSTEM FOR MAXIMUM PERFORMANCE AND PROTECTION

Increasing the concentration of inhibited glycol in your system

It is sometimes necessary to increase the concentration of a solution in your system, either to protect against cold weather, or to replace fluid lost through leakage or moisture absorbed from the atmosphere. Reconcentration can be carried out either in batch or continuous operation.

Analytical service from Dow

To ensure DOWFROST and DOWTHERM SR-1 heat transfer fluids are maintaining the proper inhibitor levels and the desired freeze point, The Dow Chemical Company provides a product analysis service for systems containing 250 or more gallons of glycol. After the system has been filled and circulated for 24 hours, an initial pint-sample should be withdrawn from the system and sent to:

DOWFROST/DOWTHERM SR-1 Fluid Testing Center
Dow Chemical U.S.A. / Larkin Laboratories
1691 North Swede Road / Midland, MI 48640

The Analytical Sample Identification Sheet should be filled out completely and returned with the initial sample. A separate sheet should be submitted for each system being tested.

After the system is in operation, it is recommended that samples be taken at least once a year. Before withdrawing a sample, the fluid should be well circulated in the system so the sample taken is representative. Sample bottles and labels are available from your Dow representative.

Approximately three weeks after the sample is received at Dow, a report will be returned showing results of the analysis, unusual or troublesome conditions (if any), and recommendations. The standard analysis includes concentration, freeze point, pH, reserve alkalinity, and appearance.

For customers who prefer to conduct their own analysis, analytical procedures are available on request. Write the address shown above for more information.

Analytical tools

The following analytical tools can be purchased through your Dow representative or distributor.

American Optical refractometer, model 7391

Refractometer measures the glycol concentration of solutions of either DOWFROST or DOWTHERM SR-1, and gives the freeze point of the fluid. This portable instrument requires only a few drops of fluid for testing, needs no adjustment for fluid temperature, and is reasonably accurate. Diluted solutions with concentrations from 0 to 55% glycol may be tested directly; however, concentrated solutions require a simple dilution procedure prior to testing. Instructions are available with the instrument.

Test kits

Kits consist of 10 test strips, a color chart, and instructions. The strips permit quick and easy approximate measures of freezing point and reserve alkalinity (inhibitor level) of solutions. They will not function if the glycol concentration is greater than 70%. (The color development of strips used to test DOWFROST may be affected by some dyes.) Color charts include graphs to help determine solution condition based on reserve alkalinity and concentration readings. More exact procedures are required to determine how much inhibitor must be added to solutions in poor condition.

ANALYTICAL SAMPLE IDENTIFICATION SHEET FOR DOWFROST* & DOWTHERM* SR-1 HEAT TRANSFER FLUIDS

IDENTIFICATION

Company
Address
City, State, Zip
Attention
DOWFROST DOWTHERM SR-1

Distributor
Address
City, State, Zip
Telephone
Sample point in unit

SYSTEM DATA

System capacity gallons. Type of system
Materials of construction
Open to air ☐ Yes ☐ No

Age of system

INSTALLATION DATA

What was in system prior to DOWFROST or DOWTHERM SR-1?
Source of water: Well or city ☐ Distilled, deionized ☐ steam consdensate ☐
How was system treated prior to filling? ☐ Drained ☐ Flushed ☐ Chemically cleaned
If cleaned, describe procedure/chemicals:

OPERATING DATA

Operating temperature range °F Filtration, if any
Age of fluid in unit Changes since last analyzed (if any)

Make-up requirements yearly

Date Signed

Send with sample to:

DOWFROST/DOWTHERM SR-1 Fluid Testing Center
The Dow Chemical Company
Larkin Laboratories
1691 North Swede Road
Midland, MI 48640

* Trademark of The Dow Chemical Company

WANT MORE INFORMATION?

Although this brochure gives you a complete overview of DOWFROST and DOWTHERM SR-1 heat transfer fluids, you may still have particular questions about them as they pertain to your system. That's where your local Dow representative comes in. He can answer those questions. Or he'll arrange for you to talk with our technical service people.

ENGINEERING AND OPERATING GUIDE FOR DOWFROST AND DOWTHERM SR-1 HEAT TRANSFER FLUIDS

DOW CHEMICAL U.S.A. **FUNCTIONAL PRODUCTS AND SYSTEMS DEPARTMENT**

AN OPERATING UNIT OF THE DOW CHEMICAL COMPANY **MIDLAND, MICHIGAN 48640**

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DOW CHEMICAL PACIFIC	P.O. Box 711, HONG KONG
DOW CHEMICAL CANADA INC.	SARNIA, Ontario N7T 7K7
DOW QUIMICA, S.A.	SAO PAULO, Brazil

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SAN FRANCISCO	2800 Mitchell Drive, Walnut Creek, CA	94598	415-944-2000
SEATTLE	Suite 522, 600—108th Ave., N. E., Bellevue, WA	98004	206-455-7250
STAMFORD	1600 Summer St., Stamford, CT	06905	203-359-3300
TAMPA	Suite 450, 5100 W. Kennedy Boulevard, Tampa, FL	33609	813-877-8300

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Form No. 173-1190-82

MONTANA
SOLAR
HOT WATER

ECONOMIC ANALYSIS OF RETROFIT SDHW SYSTEM WITH NATURAL GAS BACK-UP

DNRC

Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

Example of Simplified Economic Analysis

Retrofit SDHW System with Natural Gas Back-up

Assumptions

1. Four occupants use 70 gallons per day of 140°F hot water.
2. The existing natural gas water heater is 50% efficient.
3. The installed SDHW system and DHW energy conservation measures will reduce annual natural gas use by 75%.
4. The installed cost of the SDHW system and DHW energy conservation measures is $4000 and the homeowner pays cash for the system.
5. The SDHW system and conservation measures are installed in December 1983 and the expected lifetime of the system is at least 20 years.

Using the above assumptions the annual natural gas use for water heating before solar and conservation is as following:

$$\frac{(70\ \text{gal./day})(8.33\ \text{lb/gal.})(1\text{Btu/lb}^{\circ}\text{F})(140^{\circ}-50^{\circ}\text{F})(365\ \text{days/yr})}{0.50\ \text{efficiency}}$$

= 38.31 Million Btu/yr

The annual natural gas use for water heating after solar and conservation is the following:

(0.25)(38.31 Million Btu/yr) = 9.58 Million Btu/yr

The actual installed cost of the SDHW system is:

$4,000.00	Initial Cost
-1,600.00	40% Federal Tax Credit
- 125.00	Montana Tax Credit
$2,275.00	After Tax Credits.

The following table shows the year-by-year breakdown of forecasted natural gas prices, water heating costs and savings and returns on investment.

Year	(1) Price of Natural Gas ($/MBtu)	(2) Annual Cost Before Solar & Conservation	(3) Annual Cost After Solar & Conservation	(4) Annual Savings With Solar Conservation	(5) Cumulative Savings	(6) Annual Tax-Free Return on Investment
1984	$ 4.87	$187	$47	$140	$140	6.2%
1985	5.74	220	55	165	305	7.3
1986	6.39	245	61	184	489	8.1
1987	8.37	321	80	241	730	10.6
1988	9.02	345	86	259	989	11.4
1989	10.22	391	98	293	1282	12.9
1990	11.44	438	110	328	1610	14.4
1991	12.66	485	121	364	1974	16.0
1992	13.80	528	132	396	2370	17.4

Payback - 9 years

Column
Number

(1) Forecasts of the price of natural gas are based on the "nominal" prices given in Montana Power Company forecasts reported to the Montana Public Service Commission. Price in $/1000 cubic feet x 1.02 equals price in $/Million Btu; assumes a heat content of 980 Btu/cubic foot.

(2) 38.31 Million Btu/yr x Price of Electricity

(3) 9.58 Million Btu/yr x Price of Natural Gas

(4) Column (2) - Column (3)

(5) Year-by-year summation of Column (4)

(6) Column (4) divided by $2,275 (actual installed cost) x 100%

"Bulk" Price for Solar Hot Water

$$\frac{\$2,275 \text{ (Actual Installed Cost of System)}}{20 \text{ years} \times 38.31 \text{ Million Btu/yr} \times 75\% \text{ savings}} = \frac{\$3.96}{\text{Million Btu}}$$

Since the 1984 natural gas price is $4.87, the "bulk" price of solar hot water is $0.91 cheaper than the 1984 natural gas price.

Energy Division
Capitol Station
Helena, MT 59620
Montana Department of
Natural Resources and Conservation

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MONTANA
SOLAR
HOT WATER

ECONOMIC ANALYSIS OF RETROFIT SDHW SYSTEM WITH ELECTRIC BACK-UP

Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation

EXAMPLE OF SIMPLIFIED ECONOMIC ANALYSIS RETROFIT SDHW SYSTEM WITH ELECTRIC BACK-UP

Assumptions

1. Four occupants use 70 gallons per day of 140°F hot water.
2. The existing electric water heater is 85 percent efficient.
3. The installed SDHW system and DHW energy conservation measures will reduce annual electricity use by 75 percent.
4. The installed cost of the SDHW system and DHW energy conservation measures is $4000 and the homeowner pays cash for the system.
5. The SDHW system and conservation measures are installed in December 1983 and the expected lifetime of the system is at least 20 years.

The annual electricity use for water heating before solar and conservation is as follows:

$$\frac{(70\ \text{gal./day})(8.33\ \text{lb/gal.})(1\text{Btu/lb}^{\circ}\text{F})(140^{\circ}-50^{\circ}\text{F})(365\ \text{days/yr})}{0.85\ \text{efficiency}}$$

= 22.54 Million Btu/yr

= 6604 kWh/yr

The annual electric use for water heating after solar and conservation is:

0.25 (22.54) Million Btu/yr = 5.64 Million Btu/yr = 1651 kWh/yr

The actual installed cost of the SDHW system is:

$4000.00	Purchase Price
-1600.00	40% Federal Tax Credit
- 125.00	Montana Tax Credit
$2275.00	After Tax Credits

The following table shows the year-by-year breakdown of forecasted electricity prices, water heating costs and savings, and returns on investment.

Year	(1) Price of Electricity ($/MBtu)	(2) Annual Cost Before Solar and Conservation	(3) Annual Cost After Solar and Conservation	(4) Annual Savings With Solar and Conservation	(5) Cumulative Savings	(6) Annual Tax-Free Return on Investment (percent)
1984	$10.84	$244	$61	$183	$ 183	8.0
1985	16.99	383	96	287	470	12.6
1986	18.48	416	104	312	782	13.7
1987	21.10	475	119	356	1138	15.6
1988	22.56	508	127	381	1519	16.7
1989	23.73	535	134	401	1920	17.6
1990	25.20	568	142	426	2346	18.7
1991	26.66	601	150	451	2797	19.8

Payback-7 years

Column
Number

(1) Forecasts of the price of electricity are based on the "nominal" prices given in Montana Power Company forecasts reported to the Montana Public Service Commission and on the MPC rate increase request filed in September 1983. Price in cents/kWh x 2.93 equals price in $/Million Btu.

(2) 22.54 Million Btu/yr x Price of Electricity

(3) 5.64 Million Btu/yr x Price of Electricity

(4) Column (2) - Column (3)

(5) Year-by-year summation of Column (5)

(6) Column (4) - $2275 (actual installed cost) x 100%.

"Bulk" Price for Solar Hot Water

$2275 (Actual Installed Cost of System) = $ 6.73/Million Btu
(20 years x 22.54 Million Btu/yr x 75% Savings)

so the "bulk" price of solar hot water is $4.11 cheaper per million Btus than the 1984 electricity price.

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Helena, MT 59620
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= 22.54 Million Btu/yr

= 6604 kWh/yr

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MONTANA
SOLAR
HOT WATER

RECOMMENDED TOOLS FOR SDHW INSTALLATIONS

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Capitol Station
Helena, MT 59620

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TOOLS RECOMMENDED FOR SDHW INSTALLATIONS

*Truck with ladder/pipe rack

*Site survey tools (compass & inclinometer - necessary; sun angle and shadow "finders" - optional)

*Tool boxes and belts

*Ladders (6-foot step & extension types-usually; scaffolding-occasionally)

*Climbing safety equipment (climbing harness with tool clip-on loops, quality climbing rope, tubular nylon webbing, carabiners, etc.)

*Personal safety equipment (safety glasses/goggles, gloves, steel-toe work boots, hard hat, filter respirators, fire extinguisher, etc.)

*Wrenches (pipe, crescent, Allen, open and box end)

*Pliers (channel-lock, needle-nose, vise-grip, lineman's)

*Screwdrivers (slotted and Phillips head)

*Hammers

*Measuring tapes

*Socket set with ratchet and extensions

*Saws (hand, hack, circular, jig/sabre, etc.)

*Drill (preferably convertible straight to right-angle drill with variable speed and reverse)

*Drill bits (metal "twist," spade/Speedbore, self-feed, hole saws, etc.)

*Chalkline

*Plumb bob

*Torpedo level

*Combination and carpenter's squares

*Aviation shears/tin snips

*Combination wire stripper/cutter/crimper tool

*Files (flat and round rat-tail)

*Staple gun

*Utility/razor blade knife

*Soldering Kit (50/50 tin/lead solder, 95/5 tin/silver solder, flux and brushes, emery sand cloth, fitting cleaning brushes, tubing cutters, torch and fuel, ignitor/striker, reaming tool, sizing/rerounding tool, etc.)

*Tubing bender (for Type L copper tube)

*Trouble lights

*Extension cords

*Caulking gun

*Hand truck/cart

*Bicycle air pump or small air compressor

*Sprayer bottle (for air pressure testing with soap solution)

*Miter box or tube (for mitering rigid pipe insulation)

*Volt-ohm meter

*Thermometer (dial type or digital with various probes)

*Transfer pump and buckets (for closed-loop antifreeze systems)

*Garden hose and fittings (for draining tanks)

*Broom

*Drop cloth

*Rags

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INVENTORY AND SPARE PARTS FOR SDHW INSTALLERS

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INVENTORY & SPARE PARTS FOR SDHW INSTALLATIONS

*Solar collectors with spare glass, gaskets, etc.

*Mounting hardware (mounting channel, aluminum extrusions, stainless steel threaded rod, washers, nuts, machine bolts, lag bolts, etc.)

*Storage tanks with spare anodes

*Drain-back tanks

*Heat exchangers

*Copper tubing (commonly Types M and L in 1/2, 3/4, & 1" tube sizes)

*Copper fittings (elbows, tees, male and female adapters, regular and reducing couplers, bushings, caps, etc.)

*Unions (brass and dielectric)

*Valves (pressure relief, pressure/temperature relief, ball, gate, boiler drain, check, drain-down, tempering, etc.)

*Vacuum breakers

*Air vents

*Expansion tanks

*Pipe supports and plumber's tape

*Stainless steel hose clamps

*Circulator pumps

*Pressure gauges

*Thermometers

*Flow meters and indicators

*Pipe insulation (interior and exterior)

*Exterior paint (for protecting exterior pipe insulation)

*Tank insulation (vinyl-covered fiberglass)

*Insulated flex ducting (for air-based systems)

*Duct tape & electrical tape

*Contact cement

*Roof jacks/pipe flashings

*Roofing cement

*Silicone caulk

*Transfer fluids (glycols, silicone oil, distilled water, etc.)

*Differential temperature controls and sensors

*Electrical and wiring materials (sensor wire, romex power cable, SJ power cord, rigid & flexible conduit, electrical connectors, wire nuts, solderless crimp connectors, etc.)

Notes: 1) The actual inventory of equipment stocked depends on the type of SDHW system(s) the dealer/installer specializes in.

2) The major system components such as collectors, tanks, pumps, heat exchangers, and controls can be ordered on a job-by-job basis. However, it is advisable to select particular lines of equipment so that ordering, spare parts stocking, and maintenance are simplified.

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AN EXAMPLE BID FOR SDHW INSTALLATIONS

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EXAMPLE SDHW SYSTEM BID

The following sample SDHW system bid shows the component price breakdown for a typical closed-loop antifreeze SDHW system in a residential retrofit. The solar collectors are roof-mounted in a vertical tilt-up configuration. The assumed residence is a ranch-style house with attic and full basement. The existing water heater is electric and is located in the basement. The SDHW system will be tied into the existing water heater.

The list prices shown in the bid below are based on a 15 percent shipping and handling charge and up to a 20 percent mark-up on equipment for profit and overhead for the solar dealer/installer.

The bid is intended as an example only. Other system configurations, equipment types and sizes, shipping charges, mark-ups for profit and overhead, etc., will alter the bid results. The dealer/installer should price each installation on an individual basis and adjust shipping, mark-up, labor costs, etc., for his or her particular business situation.

EQUIPMENT DESCRIPTION	LIST PRICE	PERCENT OF TOTAL SYSTEM PRICE
Collectors & Mounting		
2 3 by 8 foot flatplate collectors with single low-iron tempered glass and selective surface absorber	$1076	
2 sets of vertical tilt-mounting hardware, threaded rod, nuts, washers, attic spanners, etc.	$138	30.7 percent
Storage Tank		
80-gallon solar storage tank, glass-lined, magnesium anode		
R-20 rigid foam insulation	$566	14.3 percent
Pumps		
Solar loop pump, 1/25-HP wet rotor cartridge circulator with cast iron housing, 16 ft head max	$104	
Water loop pump, 1/40 HP wet rotor cartridge circulator with bronze housing, 10 ft head max	$117	5.6 percent
Piping, Fittings, & Insulation		5.2 percent
80 ft Type L 3/4" copper tube	$48	
Miscellaneous copper fittings	$35	
95/5 tin-silver solder, flux, propane, pipe dope	$20	
Dielectric unions	$28	
6 ft interior R-4 elastomer pipe insulation	$60	
10 ft exterior R-7 urethane foam pipe insulation	$15	5.2 percent
Plumbing Specialties		
Diaphram-type expansion tank	$48	
Hot water tempering valve	$42	
Isolation ball valves (5)	$45	
Automatic air vent	$21	
Swing check valve	$15	
Solar loop pressure relief valve	$15	
Pressure/temperature relief valve	$8	5.0 percent

EQUIPMENT DESCRIPTION	LIST PRICE	PERCENT OF TOTAL SYSTEM PRICE
Heat Exchanger		
External counterflow type with double-wall construction and leak detection	$145	3.7 percent
Control		
Differential temperature control with sensors (2), 8/3°F on/off differentials, high storage limit shutdown	$125	3.2 percent
Monitoring Instruments		
0-100 psi pressure gauge	$10	
In-line dial thermometers (3)	$66	
In-line solar loop flowmeter	$42	2.9 percent
Hot Water Conservation Measures		
Water heater insulation jacket	$18	
Low-flow shower heads (2)	$36	
Low-flow faucet aerators (3)	$36	2.3 percent
Miscellaneous Materials		
Sensor and 120 VAC wiring and connectors	$30	
Roof jacks, silicone caulking, roof cement, exterior paint, duct tape	$27	1.5 percent
Antifreeze Transfer Fluid		
Solar grade inhibited propylene glycol (5 gallons, mixed 60/40 with water)	$50	1.3 percent
Installation Labor		
8 man-days @ $120/man-day	$960	24.3 percent
Total System Bid (before solar tax credits)	$3,950	100.0 percent

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MONTANA SDHW INSTALLERS AND SUPPLIERS

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Capitol Station
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RESOURCE LIST/MONTANA CONTACTS FOR SDHW SYSTEMS & INFORMATION

NOTE: The Department of Natural Resources and Conservation does not approve or sanction any of the following companies. The list is presented simply as an initial contact source for individuals interested in obtaining further information on solar hot water. This list is by no means exhaustive, and individuals should seek out other sources of information.

Billings Area

1) JACO Energy Brokers, Inc. (June Cole & Larry Munyan)
   111 Main St. Suite 8
   Billings, MT 59105
   252-8242

2) Solar Works, Inc. (Larry Drake & Jim Chauncey)
   2108 Broadwater Ave.
   Billings, MT 59102
   652-3770

3) Dopler Solar Construction (Pat Dopler)
   P.O. Box 54
   Red Lodge, MT 59068
   446-3021

4) Contech Distributing Co. (Fred Wilson)
   2139 Broadwater Avenue
   Billings, MT 59101
   656-3813

5) Solar Hardware (Alan & Sandra Champlin)
   217 W. Main
   Laurel, MT 59044
   628-6108

Bozeman Area

1) SunCraft Appropriate Energy Alternatives, Inc.
   (Dale Pickard & Bob Knebel)
   135 E. Main/ P.O. Box 1146
   Bozeman, MT 59715
   587-3442

2) Fowlkes Engineering (Charless Fowlkes)
   31 Gardner Park
   Bozeman, MT 59715
   587-3779

3) Brelsford Engineering (Don Brelsford)
P.O. Box 1252
Bozeman, MT 59715
587-8486

4) Homestead Alternative Concepts (Dave Williams)
322 W. Beall
Bozeman, MT 59715
587-8429

5) Solar Mountain Co. (M.J. McBeen)
Box 64
Gardiner, MT 59030
848-7280

Missoula Area

1) Energy Options, Inc. (Scott Sproull)
240 North Higgins
Missoula, MT 59801
721-2733

2) Sun House Energy Products
1400 Russell
Missoula, MT 59801
721-5549

3) South-Wall Builders (Steve Loken)
P.O. Box 8872
Missoula, MT 59807
549-7678

4) Solar Structures
132 Speedway Ave.
Missoula, MT 59602
543-7446

5) Fullerton's Plumbing & Heating
401 W. Main
Hamilton, MT 59840
363-3122

6) Sunset Solar Construction (Dick Dill)
915 Pine Hollow Rd.
Stevensville, MT 59870
777-3168

Lewistown Area

1) Eastman Solar (Kirk Eastman)
701 E. Main
Lewistown, MT 59457
538-2500

2) Fry Plumbing & Heating
418 W. Broadway
Lewistown, MT 59457
538-3237

Great Falls Area

1) Decker Engineering (Glen Decker)
808 Tenth Ave. SW
Great Falls, MT 59404
761-0362

Miles City Area

1) Solar Design (Tom Mull)
221 N. Cottage Grove
Miles City, MT 59301
232-4778

2) Solar Ray
Yellowstone Valley
Miles City, MT 59301
232-0695

Kalispell Area

1) Sunstar Solar (Jerry Brobst)
P.O. Box 786
Bigfork, MT 59911
837-4483

2) Solar Castles (O.J. Sova)
P.O. Box 1384
Columbia Falls, MT 59912
892-3582

Butte/Dillon Area

1) Dillon Refrigeration (Dan Nitshe)
332 W. Morse
Dillon, MT 59725
683-6441

2) NCAT (Ray Schott)
Box 3838
Butte, MT 59702
494-4972

3) Alexander Solar Construction (Marty Alexander)
2618 Walnut
Butte, MT 59702
782-1716

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RECENT SOLAR AGE AND SOLAR ENGINEERING AND CONTRACTING ARTICLES DEALING WITH SOLAR HOT WATER

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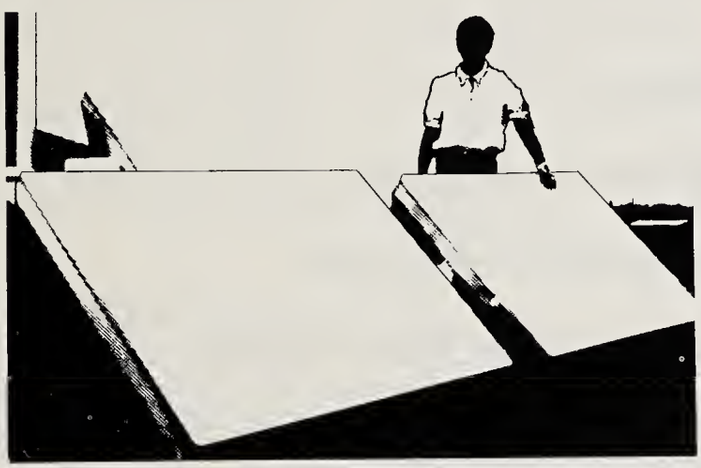

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Comparing Collectors

By Jennifer A. Adams

Take a sheet of rigid polyurethane, paint it black, cover it with polyethylene glazing, frame it in pine, and you've got an inexpensive, efficient, long-lasting, space-heating collector. Right? Wrong. Cheap, maybe; durable and efficient, no.

A collector's maximum efficiency and its durability result from the combination of materials that go into it. If the collector described above were actually tested, a closer look at the materials and performance data would reveal a very inefficient, short-lived collector.

With over 200 collector manufacturers in the market, with kits for the do-it-yourselfer, and so many different materials and configurations, decisions about collectors for a particular application can be very difficult. But by decoding available test data and knowing the limitations of the materials and how they affect performance, you'll be able to make the right choice.

Thermal Efficiency Curve

Comparing collectors based only on the ratings developed with the ASHRAE Standard 93-77 tests is like buying an automobile based only on the EPA mileage rating. But until system testing becomes a reality, the data from the ASHRAE tests are the only way to compare the thermal performance of collectors from different manufacturers for a given application.

Typical thermal efficiency curves (TEC) resulting from a plot of sample test data from the ASHRAE Standard 93-77—"Methods of Testing to Determine the Thermal Performance of Solar Collectors"—are shown in Figure 1.

Each collector is tested under a prescribed set of environmental conditions. At a constant flowrate, water is pumped through the collector, and the temperature rise across the collector is measured. The performance equation is derived from the test data and is used to find the instantaneous thermal efficiency of a collector in a specific range of conditions.

$$\eta = F_R(\tau\alpha) - \frac{F_R U_L (t_i - t_a)}{I_t}$$

η = instantaneous thermal efficiency, the useful energy divided by the available incident solar radiation

F_R = Collector heat removal factor
τ = Cover transmissivity
α = Absorber surface absorptance
U_L = Collector heat losses
t_i = Fluid inlet temperature
t_a = Ambient (outside) temperature
I_t = Incident solar radiation

The equation simply states that the efficiency for a specific set of operating conditions is the ratio of the amount of usable energy produced by a collector to the amount of solar radiation incident on the face of the collector. The maximum efficiency possible is equal to one when the collector temperature is higher than the ambient temperature. Unglazed pool collectors often operate at temperatures below ambient, resulting in efficiencies greater than one. (Here, the collector is actually gaining heat from, rather than losing heat to, the air.)

The fluid parameter is $(t_i - t_a)/I_t$, a combination of variables measured during the test. The fluid inlet temperature is varied four times to provide data in four different temperature ranges. The ambient air temperature and the incident solar radiation are kept constant. A total of 16 different data points (four points for four ranges) are plotted to produce the TEC. The fluid parameter is plotted along the x-axis.

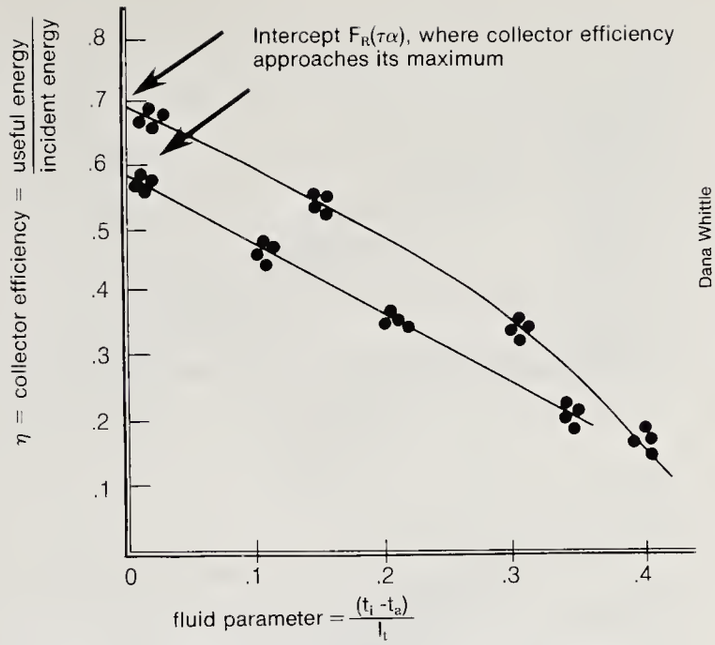
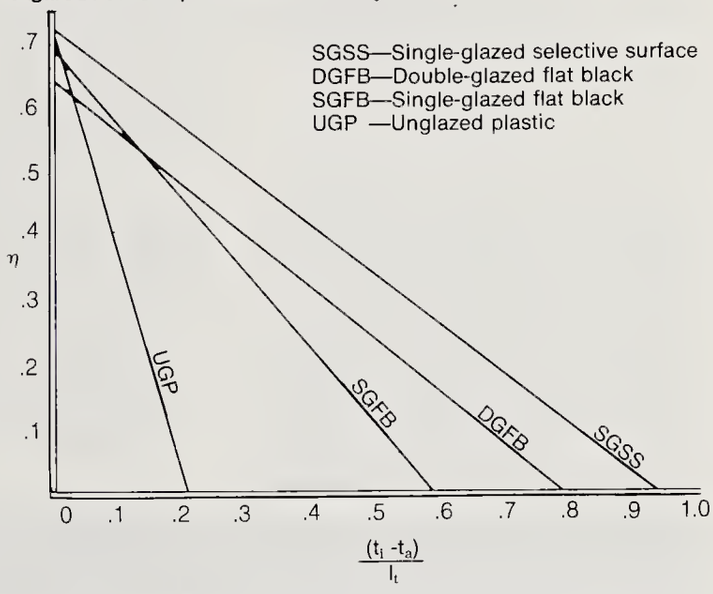


Figure 1 *Plotting ASHRAE Standard 93-77 test results generates the "Thermal Efficiency Curve" (TEC)*

Figure 2 *Four Sample Thermal Efficiency Curves*



The $F_R U_L$ product is a measure of how well the collector transfers the energy from the absorber plate to the heat transfer fluid, and how well the collector prevents heat loss to the outside. The ideal collector heat removal factor (F_R) would be equal to one. The absorber plate conductivity, plate thickness, tube diameter and spacing, and the conductivity between the tube and plate (in liquid collectors) are some of the factors that affect the value of F_R. The ideal collector would have a value of U_L equal to zero. The number of cover sheets, the surface coating on the absorber plate, and the type and amount of insulation surrounding the absorber all affect the U_L.

$F_R U_L$ is the slope of the efficiency curve. The greater the value the steeper the TEC slope, and the faster heat is lost from the collector as the collector/ambient temperature difference increases. Collectors with very steep slopes are better suited for low temperature applications, such as swimming pool season extenders. Collectors with very shallow slopes are better for high temperature applications, and for use in cold climates.

$F_R(\tau\alpha)$ is the measure of how well the collector can capture the sun's energy and transfer it to the heat transfer fluid. The ideal would be equal to one, when the glazing transmits all the energy and the absorber captures all the heat. The transmissivity is affected by

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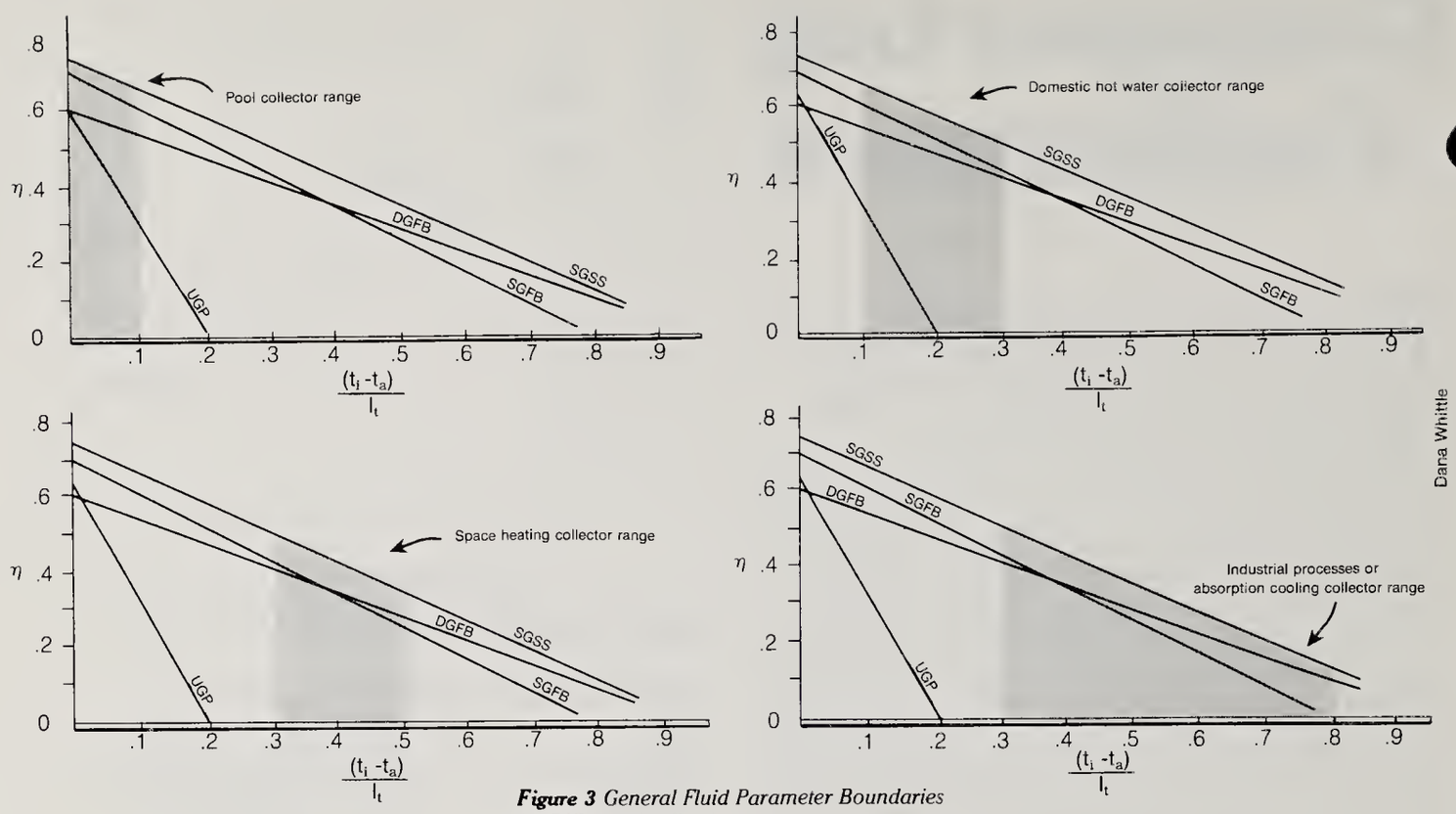

Figure 3 *General Fluid Parameter Boundaries for Different Applications*

the number of layers of glazing and the material itself. The absorptance is affected by the type of coating—selective or non-selective—on the absorber plate.

Once the test data are plotted on the graph, $F_R(\tau\alpha)$ is found at the intersection of the curve with the y-axis. That point, called the intercept, is generally regarded as the maximum efficiency of that collector. This would occur when t_i equals t_a, making the fluid parameter and heat losses equal to zero.

Figure 2 shows the curves of four sample flat-plate collectors. As the fluid parameter increases, the efficiency in each case decreases. Figure 3 shows the general boundaries for different collector applications. The cloudier and colder your climate, the further you should look towards the right side of each range.

Using the TEC

The output of a collector at a given instant can be determined by using the TEC. Two or more collectors can be compared using a given fluid inlet and ambient temperature, and incident solar radiation. The TEC can *only* tell the relative difference between collectors in that particular application. It cannot tell you directly how a collector will perform on a daily or yearly basis without algorithms or computer simulations.

Example: You are looking for a domestic hot water collector to be used in Philadelphia on a year-round basis. You are anticipating an inlet temperature of 110°F, an average summer ambient of 78°F, and an average winter ambient of 45°F. The average hourly radiation during the winter collection hours of 9 to 3 (from Table 1) at 40° latitude is 221 Btu/ft², and in the summer collection hours from 8 to 4 is 224 Btu/ft².

$$\text{winter fluid parameter} = \frac{110° - 45°}{221} = 0.29$$

$$\text{summer fluid parameter} = \frac{110° - 78°}{224} = 0.14$$

Projecting the fluid parameters vertically on the graph, the relative efficiencies of the four collectors can be compared. The unglazed collector is inappropriate for this application. The double-glazed flat-black collector performs significantly better than the single-glazed flat-black in the winter, with slightly less efficiency in the summer. The single-glazed selective-surface collector outperforms them both.

The next step would be to have the dealers of the three remaining collectors run computer simulations for each system in your application, producing a cost per Btu delivered from each square foot of aperture area. Compare the costs.

TEC limitations

The TEC curves should not really be drawn with a thin line, but rather with a thick bar that reflects the ±5 percent error in the test data. When curves are directly compared, this range should be remembered. Test results of F_RU_L and $F_R(\tau\alpha)$ are not included by manufacturers as guarantees of the collector performance. They are provided for the same reasons that the EPA mileage ratings are advertised with automobiles. Just because the car says it will get so many mpg, that doesn't mean it will (as most of us have found out). Comparing TEC's is only one part of choosing a collector. One should also compare the cost and the collector materials.

Cover materials

Collector covers transmit sunlight through to the absorber plate and trap its energy there after it has been converted to heat. The ideal glazing would be transparent to shortwave light energy but would be highly reflective to longwave thermal energy emitted by the absorber. It would have a low absorptivity of both light and heat energy, be highly resistant to surface scratching by dust, and strong enough to resist breakage by hail. Self-supporting, it must be able to carry wind and snow loads (check local codes for expected loads). It would be resistant to ultraviolet (UV) and high temperature degradation, have a low coefficient of thermal expansion, and have a long lifetime. It should remain attractive over that lifetime. The choices are regular glass, low-iron glass, acrylics, polycarbonates, fiberglass reinforced polyesters (FRP), fluorinated ethylene propylenes (FEP), and polyvinyl fluorides (PVF) (Table 2).

Glass still remains the primary choice in glazing active collectors. Not subject to degradation, it would have an infinite life (in building terms) if it were unbreakable. Only tempered glass should be used on collectors. Low-iron glass has a high transmissivity, which it retains through its life. Glass is virtually opaque to infrared

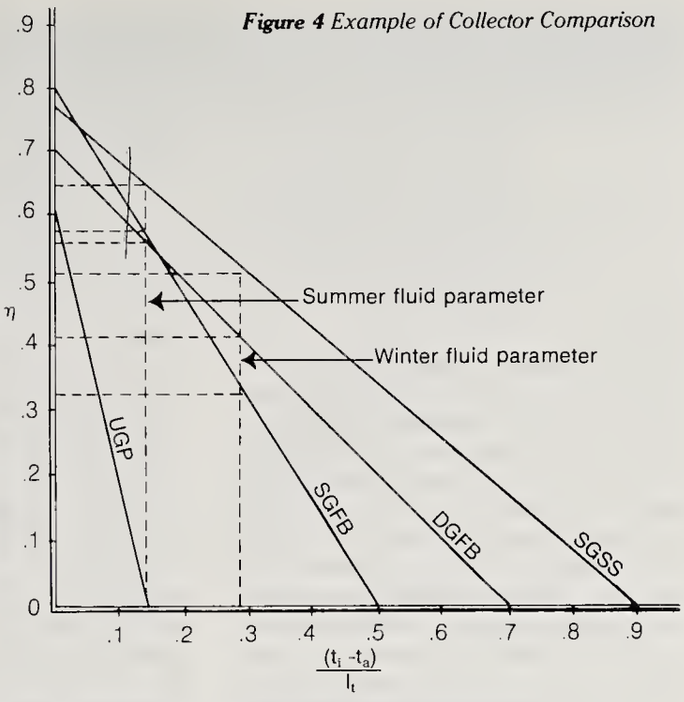

Figure 4 *Example of Collector Comparison*

Dana Whittle

radiation. Its biggest plus to the market is its appearance.

Plastics have a lower cost in some cases, and good impact strength in others. But abrasion, degradation, and expansion can be major problems. Acrylics or polycarbonates should not be used as exterior glazings in dry dusty areas because they can scratch easily. Many plastics are highly transmissive to longwave infrared (IR) radiation, letting much of the absorber's energy escape.

Most collectors are available in single-glazed models; some are available with double glazing. The higher the anticipated operating temperature of the collector, the greater the need for two layers of glazing. The number of layers is chosen with the type of absorber coating. A selective coating is usually paired with one layer of glazing, and a non-selective surface is coupled with one or two layers. A few collectors are available with a selective surface and two layers. Two layers are recommended in high wind speed areas and in areas of low winter ambient temperatures.

If the collector operating temperature is less than 150°F, only one cover may be necessary, with two covers often desired for temperatures above 180°F. The difference in temperature between the plate and the ambient is a measure of the need. If the Δt is less than 10°F, no cover is necessary. Between 10° and 60°, one cover is recommended; between 60° and 100°, two covers are recommended.

Absorber coatings

Absorber plates are coated with surfaces that absorb as much sunlight as possible, converting it to heat. "Selective surfaces" try to prevent reradiation of that infrared radiation back through the glazing. The characteristics of the coating affect the TEC intercept and slope. The greater the absorptance, the greater the efficiency. The smaller the emissivity (ϵ) of a surface, the less heat is lost through reradiation. The ideal surface would have an absorptance of one but an emissivity of zero. It would be resistant to degradation by moisture, UV, high temperatures, and temperature cycling. The choices are flat-black and selective paints, and electroplated or chemical bath selective surfaces

Table 1: Values of incident solar radiation on solar collectors facing due south and fixed at the angle of the latitude*

	24° North Latitude		32° North Latitude		40° North Latitude		48° North Latitude		56° North Latitude	
Solar Time	Dec 21	June 21	Dec 21	June 21	Dec 21	June 21	Dec 21	June 21	Dec 21	June 21
6 am/6 pm		12		16		18		19		19
7 am/5 pm	9	73		76		77		77		76
8 am/4 pm	116	142	90	143	45	142		140		137
9 am/3 pm	198	204	180	204	152	202	98	198	4	193
10 am/2 pm	258	253	244	251	221	243	180	244	95	238
11 am/1 pm	295	283	282	282	262	278	226	273	154	267
12 noon	308	294	295	292	275	289	241	285	173	276

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*including diffuse radiation (Reprinted with permissions of ASHRAE)

Table 2: Collector glazings

Glazings	Temperature Applications Low	Medium	High	Disadvantages	Expected Life	% Solar Trans.	% IR Trans.	Max. Service Temp. °F
Low Iron Glass	i,o	i,o	i,o	—	>50 yrs.	91	<2	400-600
Acryiic	i,o	o	—	e,s	25+	89	<6	160-200
Polycarbonate	i,o	o	—	e,y,s	10-15	74	<6	200-260
FRP	i,o	o	—	w,e,y	8-12	87	2	200
FEP	i	i	i	w,e	20	96	58	400
PVF	o	—	—	w	5-10	90	58	225

i=recommended inner glazing; o=recommended outer glazing; —=not recommended; e=expansion; w=wrinkling; y=yellowing; s=sagging.

Table 3: Absorber coatings		
Coating	α	ϵ
Non-selective black paint	.90-.98	.68-.90
Selective black paint	.90-.97	.11-.30
Black chrome electroplate	.87-.96	.06-.25
Black copper chemical bath	.88-.93	.12-.20
Black nickel electroplate	.87-.96	.06-.12
Iron oxide chemical bath	.84-.90	.07-.35
Unsurfaced EPDM	.90	.90

(Table 3).

Low temperature applications do not require the added cost of more efficient selective surfaces; flat-black or non-selective surfaces are adequate. The higher the operating temperature expected, the greater the need for a selective surface. Selective surfaces withstand the higher temperatures better, so they are more durable. They also increase the collector efficiency dramatically by reducing the collector heat losses (U_L) as the collector/ambient temperature difference increases. Electroplated and chemical bath selective surfaces are more durable than painted surfaces because they are integral with the absorber.

Absorber plate

The absorber plate transfers the just-converted heat to the heat transfer fluid before it is lost to the surroundings. The better the plate does its job, the less heat is lost from the collector, and the more nearly horizontal the TEC slope. The ideal plate would be made of a readily abundant material that is lightweight but strong, and easy to manufacture. It would resist corrosion and have a high thermal conductivity. Able to withstand a service temperature of 200°F and stagnation temperatures of 400°F, it would withstand thermal cycling of −20°—400°F.

Absorber plates are available in plastics, carbon and stainless steel, aluminum, and copper (Table 4). The thermal conductance of the plate is based on the conductivity of the material used and the thickness of the plate. The diameter of the tubes, how close they are together, and the conductance of the joint between the tubes and the plate are issues particular to liquid collectors. The plate configuration, with the goal of increased heat exchange surface area in the same square foot collector size, is particular to air collectors.

Copper is the material used in the majority of liquid collectors because of its high thermal conductivity and durability. It is almost twice as conductive as aluminum, and eight times as conductive as steel. But tradeoffs must be made between conductance and cost. Even with its very low conductivity, plastic has successfully entered the market for low to middle temperature applications. Treated against heat and UV degradation, the lower conductivity can be made up with a greater collector area.

The tubes used in liquid collectors are usually ¼- to ½-inch in diameter, and spaced 2- to 6-inches on center. Larger diameter tubes are recommended for those areas with hard water. Scale buildup will have a slower effect in larger diameter tubes. Thermosiphoning systems should also use the larger diameters to reduce pressure drops.

The tubes are attached to the plate in three ways (Figure 5). The "integral-tube" is formed at the same time as the plate (A). "Tube-on-plate" absorbers are made of separate plate and tubes, which are continuously soldered or welded together (B). "Tube-in-plate" is a fabrication process where the tubes are pressed into the plate, with a continuous contact between the two (C).

Good thermal performance is dependent on a highly conductive bond between the tube and plate. The best, but more expensive, is the integral. A relatively new ultrasonic welding process is being adopted by the industry, which produces good solid contact between the tube/plate. Thermal cement, low temperature solders, clips, clamps, and wires are unacceptable, because they do not provide an adequate, durable thermal bond.

Copper tubes are recommended in locations with highly corrosive waters. Aluminum and steel tubes may be used in closed systems, with properly treated heat transfer fluids. Only copper or stainless steel can be used safely in an open system.

Tube-in-plate and tube-on-plate designs have the advantage of being able to use copper as the tube material and a less expensive material as the plate. As long as there is no water to cause galvanic corrosion between the two dissimilar metals, a less expensive plate is possible. Copper tubes in aluminum plates are popular. Collectors with two-metal plates should be totally protected from the elements and sealed against leakage, condensation, or high humidity. Plates of dissimilar metals should never be used in unglazed collectors.

Air collectors have a lower value of F_RU_L than liquid collectors, due to a thin film of air which slows the transfer of heat from the plate to the air. Creating air turbulence helps to "scrub" the heat off the plate, and provides more surface area for the air to pass. Because of the increased surface necessary, copper is rarely used as an air absorber plate. Methods to increase the plate surface range from corrugated sheets (D) to metal screens (E) to fabric matrices (F) (Figure 5). Passing the air above or through the plate can increase the surface area but can also increase the heat loss through the glazing.

Table 4: Absorber materials and conductivities	
Material	Conductivity (Btuhr/ft² °F in)
Aluminum	56-90 (depending on alloy)
Copper	227
EPDM	2.4
Plain carbon steel	30
Stainless steel	10

Insulation

The collector's insulation slows the collector side and back heat loss. With other factors held constant, more insulation produces a flatter TEC slope and a collector that will perform better even as the collector/ambient air temperature difference increases. The best insulation would be able to withstand normal operating and stagnating collector temperatures. The well-insulated collector would have a high R-value layer of insulation across the back and sides. The materials used for collector insulation are mineral fiber, glass fiber, and plastic foams (Table 5).

The major issue in collector insulation is the expected operating temperature. Temperatures of −20°F—250°F during the normal operation of the collector should

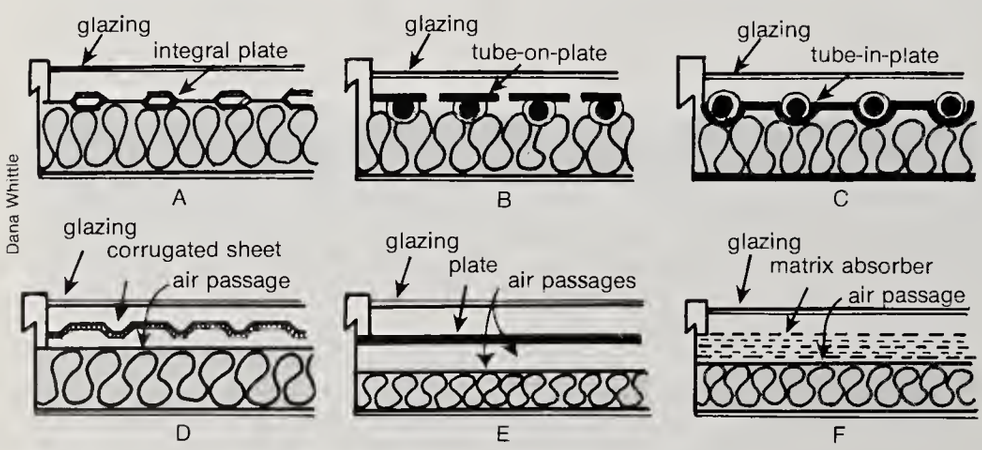

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Figure 5 Examples of Various Absorber Plates and Collector Construction

Table 5: Insulation

Material	Conductivity (Btuhr/ft²°F in)	Upper Temperature Limits (°F)	Coefficient of Linear Expansion (in/in °F)
Mineral fiber board	.38	1000	not applicable
Glass fiber board*	.22	1000	not applicable
Polystyrene	.20	165	35×10^{-6}
Polyurethane	.16	220	$26 - 60 \times 10^{-6}$
Polyisocyanurate	.17	250	50×10^{-6}

*low or no binder content

not cause the insulation or its "binders" to degrade. Volatile materials in insulation can boil off and condense on the glazing and absorber. This reduces the transmittance, absorptance, and R-factor. Some Freon-blown foams (polyurethane and isocyanurate) have been reported to outgas hydrofluoric acids, which attack metal in the collector. Gases in polyurethanes can expand, swelling the insulation and distorting the absorber plate. Once the bubbles in the foam break, the R-value is drastically reduced; the material shrinks and leaves gaps around the perimeter of the collector. Polystyrenes cannot withstand even a short period of stagnation. Reports of polystyrene shrinking from six to two feet have been heard.

Urethanes alone are fine for low-temperature applications where flat-black paints and plastic covers (or no covers) are used—as long as the collector will never stagnate. Many manufacturers place a minimum of ½-inch of high-temperature fiberglass insulation between the urethane and the absorber, so that the former is never exposed to the plate temperatures in medium temperature applications.

Only "high temperature" fiberglass is recommended when fiberglass is specified, because the binder in regular fiberglass will outgas. Many manufacturers are using unbonded fiberglass. An air gap between the absorber and a foil-faced insulation (which reflects heat back to the plate) will help further isolate the insulation from the absorber temperatures.

The insulation around the collector perimeter will have little protection from exposure to the heat and UV degradation, so it must be a tough material. Edge insulation is very important in reducing heat losses through the sides of the collector, but it is often omitted. Choose only those collectors with side insulation for medium- and high-temperature applications.

Collector housing

The case around the collector interior protects the absorber and the insulation from the elements. The ideal housing would not only be attractive but would also be structurally sound, watertight, fire-resistant, capable of being mechanically connected to its supports, durable, and lightweight. Cases are available in galvanized or painted steel, extruded or folded sheet stock aluminum, and molded or extruded plastics, which are treated to resist UV degradation. Mill finish or anodized aluminum is the most expensive of the choices, but it is also the most durable and maintenance free. Galvanized steel has been known to corrode where the stock has been cut or bent in the manufacturing process.

Climate is the major issue when looking at the different materials used for housings. Areas near the ocean, where the level of salt in the air is very high, areas of high sulfur dioxide, or areas of high humidity, are tough on collector housings. In these areas, the choice must be made carefully. Inspections of systems in place in your area should give you an idea of how different collector materials are reacting. ☼

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By Dick Oswald

Often the most difficult decision facing the potential buyer or specifier of a solar energy system is how much credence to give performance claims. In many cases, the customer's inability to get an impartial, low-cost evaluation of these energy savings claims is the main reason that a purchase falls through. Here is a simple method designed to help overcome the problem. The person shopping for the right system can use it to judge the reasonableness of performance claims for active solar equipment. The method works for both domestic hot water and space heating systems, but keep in mind that it will give you *rough estimates only*. Designers and specifiers of large or complex systems should always use detailed design tools, such as the FCHART computer program.

Dick Oswald is an energy consultant with Northeast Utilities, Enfield, CT.

Finding the amount of solar radiation available is the place to start in estimating system performance. This value varies widely across the United States, from lows in the Lake Erie region of Pennsylvania and New York to highs in the desert of southern Arizona and southeastern California. Table 1 shows the average yearly radiation for several sites, including these high and low areas. The three values given for each location indicate the radiation available for different collector tilts.

Most solar collectors are mounted at tilt angles within 10 degrees of the local latitude, so it is this tilt value that should be used in most cases. As you can see from Table 1, this is also the surface that receives the greatest amount of radiation over an entire year. Values for vertical surfaces are useful in assessing wall-mounted collectors; horizontal surface values are the most commonly available. For locations other than those listed, choose the city with the most similar climate and roughly the same latitude.

Table 1: Annual Radiation Available for Various Collector Surfaces (Values in Btu per square foot per year)

Location	Horizontal Surface	Tilt = Latitude	Vertical Surface	Latitude
Atlanta	491,000	518,000	375,000	33.6
Binghamton, N.Y.	364,000	379,000	318,000	42.2
Boston	403,000	437,000	364,000	42.4
Denver	572,000	656,000	503,000	39.7
Houston	493,000	510,000	343,000	30.0
Los Angeles	582,000	630,000	444,000	33.9
Miami	538,000	559,000	353,000	25.8
Minneapolis	427,000	473,000	406,000	44.9
Phoenix	682,000	744,000	508,000	33.4
St. Louis	484,000	522,000	402,000	38.7
Seattle	384,000	486,000	365,000	47.4

Note: Finding values for tilt = latitude requires computer design tools or tedious hand methods. Values for horizontal and vertical surfaces in many locations can be found in *Passive Solar Design Handbook*, volume 2, by J.D. Balcomb et al.

Solar water heating systems

Domestic hot water systems are by far the most widely used solar energy systems, and many of them around the country have been monitored. These studies have all produced similar results. Solar DHW system efficiencies (i.e., the amount of energy delivered from the solar system divided by the solar radiation incident on the collectors) typically vary from 20 to 37 percent,

Use this method to spot exaggerations about solar energy systems. At the same time, the test will give you a wealth of valuable information when you're shopping for hot water and space heating equipment in any locale.

A Simple Test of Performance Claims

with an average value of 27 percent. The results also show that the parasitic energy used to operate pumps and controls is usually in the range of 5 to 10 percent of the solar energy delivered to the load. Subtracting this parasitic energy from the delivered solar energy indicates that net DHW system efficiencies range from 18 to 35 percent, with an average value of 25 percent.

Combined with the values of available solar radiation, the system efficiencies show that in a typical climate such as St. Louis', solar DHW systems will provide an average of 130,000 Btu of energy for each square foot of collector area, when collector tilt roughly equals latitude.

Space heating systems

Researchers have also monitored solar space heating and combined space and water heating systems. Their findings: system efficiencies range from 14 to 37 percent for both types of systems, with an average efficiency (including the effect of parasitic power) of about 23 percent. This means that a combined space and water heating system with a collector tilt of about 39° in St. Louis will provide about 120,000 Btu per year per square foot of collector.

It is important to note that for systems that supply space heating only the system output equals the system efficiency multiplied by the solar radiation available during the heating season only. For collectors tilted at an angle equal to the latitude, this value is approximately 55 percent of the year-long total, given a typical heating season running from October through April. For vertical collectors, 60 to 65 percent of the annual radiation is available during the same heating season.

Conventional fuel savings

Now you know how to gauge the energy output of solar systems. But these estimates do not necessarily equal the actual savings in conventional energy. Except in the case of electricity, the conventional energy being replaced is supplied to the heating system at efficiencies below 100 percent. Therefore, the actual conventional fuel savings from the solar equipment are *greater* than its estimated energy output. Calculate conventional fuel savings by dividing the solar output by the fractional efficiency of the conventional energy system. Typical efficiencies for space and water heating are shown in Table 2.

Table 2: Typical Efficiencies of Conventional Energy Systems

Type of System	Fractional Efficiency*
Hot Water Heating	
Gas, Oil	.85
Electric	1.0
Space Heating	
Gas, Oil	.70
Electric	1.0
Combined Space and Water Heating	
Gas, Oil	.75
Electric	1.0

*The efficiencies listed here do not include standby and delivery losses; they reflect the overall "burner" efficiency and are somewhat higher than typical overall efficiencies.

Monetary savings

The savings from a solar energy system are often expressed in dollars rather than in Btu's. To evaluate these claims, you must convert the energy savings to a dollar savings estimate based on the type and cost of the conventional fuel to be replaced. Table 3 gives the equations you need to change standard unit energy costs to a useful comparison unit—dollars per million Btu.

To estimate dollar savings from the solar energy system, plug your conventional energy cost into the appropriate equation from Table 3 and multiply the result by your estimated conventional fuel savings.

Final remarks and examples

The two examples that follow illustrate how this quick evaluation method works. But before you look at them, remind yourself of the appropriate use and limitations of such a quick estimate. First of all remember that it is just a rough estimating technique and certainly not a design tool. Also keep in mind that the values presented here for system efficiency are averages obtained from a relatively small sample of monitored systems. Some systems will fall below the average value and some will provide higher efficiencies. The point of the method is to reassure a person with little knowledge of solar system performance and to weed out those few salesmen and companies whose wildly exaggerated claims have hurt the entire solar industry.

Example 1

A family in suburban St. Louis is considering buying a roof-mounted solar water heating system. The local installer says that the three-panel, 70-square-foot system he wants to sell them should save them $200 per year.

Evaluation: The collectors will be mounted at an angle roughly equal to the latitude. The formula we use looks like this:

Radiation (Btu/ft²/year) × Efficiency = Output (Btu/ft²/year)

Plugging in the appropriate numbers we get:

$$\frac{522{,}000 \text{ Btu}}{\text{ft}^2 \text{ year}} \times .25 = \frac{130{,}500 \text{ Btu}}{\text{ft}^2 \text{ year}}$$

Since the system has 70 square feet of collector area, this equals

$$\frac{130{,}500 \text{ Btu}}{\text{ft}^2 \text{ year}} \times 70\text{ft}^2 = \frac{9.1 \text{ million Btu}}{\text{year}}$$

from the solar DHW system. Since they currently heat water with electricity, the conventional fuel savings would be:

$$\frac{9.1 \text{ million Btu/year}}{1.0 \text{ efficiency}} = \frac{9.1 \text{ million Btu}}{\text{year}}$$

With electricity costing 7¢ per kWh, the dollar savings would be

$$7¢ \times 2.93 = \frac{\$20.51}{\text{million Btu}}$$

$$\frac{\$20.51}{\text{million Btu}} \times \frac{9.1 \text{ million Btu}}{\text{year}} = \$187/\text{year}$$

This is reasonably close to the savings offered by the installer and the homeowner should feel comfortable buying the system if all the other factors are favorable. (Actually, a system efficiency of 26.8 percent would provide the savings the installer claimed and is certainly reasonable.)

Table 3: Conventional Fuel Costs

Type of Fuel	Equation for Conversion
Gas	$\frac{\$}{100 \text{ ft}^3 \text{ or therm}} \times 10 = \frac{\$}{\text{million Btu}}$
Oil (#2 residential)	$\frac{\$}{\text{gallon}} \times 7 = \frac{\$}{\text{million Btu}}$
Electricity	$\frac{¢}{\text{kWh}} \times 2.93 = \frac{\$}{\text{million Btu}}$

Example 2

A small business in southern New York is being offered 100 square feet of wall-mounted collectors for a solar space heating system. The solar company says that its system will shave $600 from the business' oil bill each year.

Evaluation: A vertically mounted collector in southern New York (near Binghamton) operating at an average efficiency of 25 percent during a heating season in which 65 percent of the annual radiation strikes the collectors would produce

$$\frac{318{,}000 \text{ Btu}}{\text{ft}^2 \text{ year}} \times .65 \times .25 = \frac{51{,}675 \text{ Btu}}{\text{ft}^2 \text{ year}}$$

The 100-square-foot system will produce

$$\frac{51{,}675 \text{ Btu}}{\text{ft}^2 \text{ year}} \times 100 \text{ ft}^2$$

$$= 5.2 \text{ million Btu/year}$$

Given the 70-percent efficiency of the oil heating system, this translates into a fuel savings of

$$\frac{5.2 \text{ million Btu/year}}{0.7}$$

$$= 7.4 \text{ million Btu/year (oil)}$$

Since the cost per Btu of oil is

$\$1.25/\text{gallon} \times 7.0 = \$8.75$ per million Btu,

the annual savings from the solar energy system will be about

$$\frac{7.4 \text{ million Btu}}{\text{year}} \times \frac{\$8.75}{\text{million Btu}}$$

$$= \$64.75/\text{year}$$

The solar company's claim is almost 10 times higher than our rough estimate—it borders on the fraudulent. Obviously the business owner should reject the proposal.

Sources of information

"Monitored Performance of 18 Solar Hot Water Systems in the National Solar Data Network," Annual Meeting of the American Solar Energy Society (ASES), Houston, June 1982.

"TVA Comparison of F-Chart Predictions with Experimental Results for Domestic Hot Water Systems in Chattanooga," Annual Meeting of ASES, Houston, June 1982.

"Wisconsin Collector Efficiency Study," Annual Meeting of ASES, Houston, June 1982.

L. Doak and G. Gervasio. "Long-Term Performance Trends for 10 Solar Systems Monitored by the National Solar Data Network," *Proceedings of the ASME Solar Energy Division Third Annual Conference on Systems Simulation, Economic Analysis/Solar Heating and Cooling Operational Results,* Reno, 1981.

R.S. Skidmore and J.T. Smok. "Thermal Performance of Solar Energy Space Heating Systems," *Proceedings of the Solar Heating and Cooling Systems Operational Results Conference,* Colorado Springs, Colo., 1979.

The Solar Hot Water System Rating Test

The stage is set behind sealed laboratory doors. Inside the test chamber, temperatures are tightly controlled. Equipment is wired to recorders and meters. Artificial lights are turned on to simulate the sun. A trial begins that will rate the performance of a solar water heater.

By William J. Putman

As a member of the solar industry for the past six years, I have watched solar stride forward despite formidable obstacles. A new procedure for testing domestic hot water systems now before our industry will, if it proves to be acceptable, greatly benefit solar or, if unsuccessful, will have a far-reaching negative effect. While the debate has already begun, the *actual mechanics* of performing a systems test and the interpretation of the data gathered are shrouded in mystery. I will explain how the ASHRAE Standard 95-1981 is applied in one certification program.

To perform a test, we must first define the type of system so that its energy output is correctly measured and reported (See Defining the Systems).

The system, delivered to a test lab, is placed in an environmental chamber. Instruments are installed to monitor the ambient air temperature, and to measure the cold supply water temperature, the temperature of the water drawn from the system, the number of gallons of hot water drawn from the system, and a set of Q numbers.

The Q numbers are:

Q_{NET}: The net amount of daily energy provided from the sun in a solar hot water system.

Q_{NET} is calculated as follows for solar plus supplemental systems:

$$Q_{NET} = Q_{DEL} + Q_{LOSS} - Q_{AUX} - Q_{PAR}$$

and for solar only and solar preheat systems:

$$Q_{NET} = Q_{DEL} - Q_{PAR}$$

Q_{DEL}: The daily total delivered energy of the solar hot water system (including energy supplied by electrical or gas backup for solar plus supplemental).

Q_{LOSS}: The daily standby losses of the auxiliary tank; set to 3.1 kWh for electrical backup and 14.9 kWh for gas backup as noted in ASHRAE Standard 95-1981, Appendix C.

Q_{AUX}: The daily backup energy for electrical or gas heating used by the solar hot water system to deliver the required amount of hot water. It is the auxiliary energy use.

Q_{PAR}: The daily energy used to supply power to pumps, controllers, and trackers (if required) to operate the solar hot water system. These are parasitic energy losses.

Q_{CAP}: The energy storage capacity of the backup tank. Used only for solar plus supplemental systems and measured at the start of the test.

Q_{RES}: The reserve capacity of the system (the energy remaining after the last day's load is drawn off at the end of the test).

Q_{DL}: The desired load or test load on the solar heating system.

An important point to make before explaining how ASHRAE 95-1981 is used to test systems is that the standard is a cookbook of how to. It does not specify the environmental and DHW load conditions. Whoever contracts for the testing can specify whatever environment and/or load conditions they desire. Usually, industry rating organizations specify these conditions. Two have announced certification programs—the Solar Rating and Certification Corporation (SRCC) and the Air-Conditioning Refrigeration Institute (ARI). SRCC currently has the most publicized system test program, so I will use its environment and DHW load conditions to describe the system test method.

SRCC requires that the test day provide 1500 Btu/ft² of simulated solar radiation to a 45° aperture plane. That is, the "sun" is at a 45° angle above the horizon. The 1500 Btu/ft² is provided over a nine-hour period, starting at 8:00 a.m. and ending at 5:00 p.m., at a specified irradiance profile with incident angles ranging from 0° to 60°. In other words, the simulated solar day looks like an equinox day (March 21st or September 21st) in most ways with the solar simulator required to move like the sun. This irradiance level was chosen since it approximates the yearly average daily radiation total for the top 10 population centers in the United States (1980 census). The ambient air temperature and supply water temperature during testing are 22°C (71.6°F). The average water supply temperature may be higher than the national average; however, by keeping the water supply temperature equal to the ambient temperature, all energy gains are strictly from solar input.

During the solar simulation period, a wind of 7.6 mph blows across the collectors. In the SRCC program, the daily total energy load drawn from the system is 40,119 Btu (11.76 kWh) taken in three equal energy draws of 13,373 Btu (3.92 kWh) at 8:00 a.m., noon, and 5:00 p.m. A draw of 13,373 Btu is equal to approximately 33 gallons of water heated from 71.6°F to 120°F. SRCC allows the manufacturer to specify the setpoint (T_{SET}) of the auxiliary supply thermostat at 120°F or greater.

Let's assume we are testing a solar plus supplemental system. This could be a common active system with collectors, solar storage tank, plus a separate gas-fired backup tank. Alternatively, a thermosiphon or ICS system that incorporated

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Mark Riffle

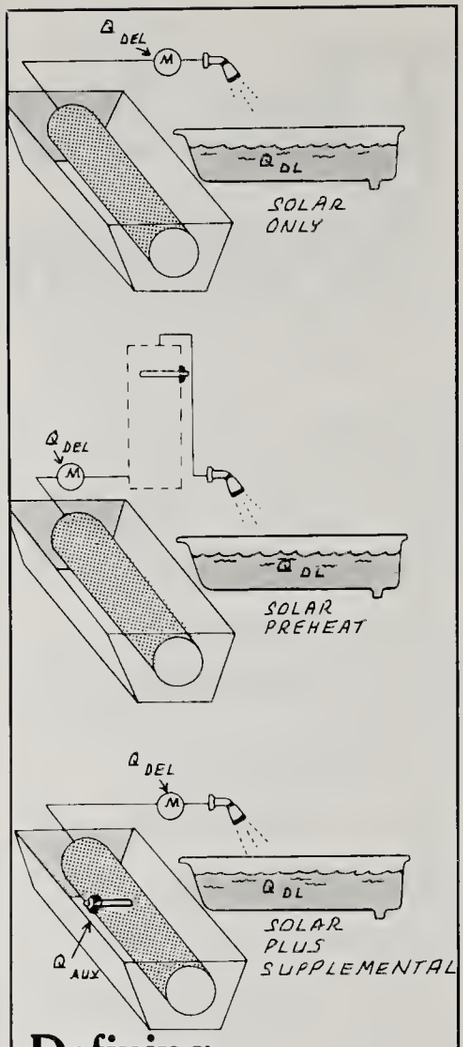
an electrical backup element in the storage tank would also be classified as solar plus supplemental. (The storage tank is then also considered to be the backup tank.)

The first step in the procedure is to determine the energy storage capacity of the backup auxiliary tank (Q_{CAP}). Q_{CAP} is determined by letting the auxiliary heating unit heat the water in the backup tank until the thermostat controller senses that the water temperature has reached T_{SET}. The auxiliary energy service is then disabled, and the tank is allowed to sit for 10 minutes. After 10 minutes, water is withdrawn until the outlet temperature from the backup tank drops below 35°C (95°F). SRCC requires that each 13,373 Btu drawn on the last day of the test be at a minimum of 113°F. Q_{CAP} tells the supplier if the system will meet this requirement. If the system supplier's backup tank cannot meet this capacity, the supplier must either increase the size of the backup tank and/or raise the T_{SET}, or fail to be certified. It is important to note the Q_{CAP} test is only necessary for solar plus supplemental systems—it represents the auxiliary energy storage capacity of the backup tank.

Once the backup tank performs satisfactorily, the next step for all types of systems is to preheat the water in the solar storage tank. The preheat temperature is usually chosen by the test laboratory and is determined by the number of gallons of storage and the size of the collection area. If chosen correctly the preheat temperature can decrease the number of days required to complete the system test. Once preheating is completed, the test begins.

Starting time is 5:00 p.m. The system sits overnight while the test laboratory monitors the ambient temperature, and parasitic and auxiliary energy use. At 8:00 a.m. the first day, a wind of 7.6 mph is applied to the collector and the solar radiation simulation period begins. The solar radiation is either simulated by a solar irradiance simulator, which is a light source, or a thermal electrical resistance heater. Also at 8:00 water is drawn from storage at a flowrate of 3.17 gallons per minute. When 13,373 Btu of energy are drawn from the system (or if the delivery water temperature falls below 35°C (95°F), the draw is terminated. Whenever the draw falls below 95°F, the energy in the draw is measured and reported; remember, though, that for solar plus supplemental, on the last day of the test, if the hot water temperature falls below 45°C (113°F), the system fails. The water drawn from the system is replaced with 71.6°F water.

The second draw is made at noon, and at 5:00 p.m. the final draw of the day is made.



Defining the Systems

ASHRAE Standard 95-1981, the consensus standard test method, has three categories to define DHW systems: solar only, solar preheat, and solar plus supplemental. A solar only system is exactly that; all the hot water supplied must be by solar and from no other source. Solar preheat is a retrofit system. This type of system includes everything but the backup electric- or gas-heated tank. Solar plus supplemental represents a system that comes with everything, including the auxiliary backup tank. This can be an electrical element in the solar storage tank or a separate tank.

Almost all hot water systems, including thermosiphon and integral collector storage (ICS) systems, *can fit into any one of the three categories.* It depends simply on whether or not the system supplier specifies an auxiliary heating backup. If so, will the backup be included as part of the system (solar plus supplemental) or will an existing tank be used (solar preheat)?

At 5:00 p.m., the simulated sun sets as occurs outdoors. The complete day of the systems testing is then finished and the Q

numbers are calculated. However, the test is not over. The test day is repeated until *convergence* or until the fourth day of testing is completed, whichever occurs first. Convergence for solar plus supplemental systems, as defined by ASHRAE Standard 95-1981, occurs when the auxiliary energy (Q_{AUX}) used by the system is within 3 percent of the value of the previous day. For solar-only and solar-preheat systems, convergence is reached when the daily solar fraction (percentage of solar energy supplied relative to the standard load of 40,119 Btu) is within 3 percent of the value on the previous day. All this means is that one must wait for the system to achieve thermal equilibrium. The 3 percent convergence requirement is very strict and requires tight control on the environment encountered by the system during testing. Consequently, ASHRAE 95-1981 requires that all testing be conducted indoors. The final Q number values are determined on the day convergence is reached. If convergence is not reached on the fourth day, the average of the test results for days three and four are used.

On the final test day after 5:00 p.m., Q_{RES}, the reserve capacity of the system, is determined. Q_{RES} represents the leftover energy in the system at the end of the day and is measured by disabling the auxiliary element, followed by drawing water out of the tank until the water from the tank is within 3°C (5.4°F) of the supply water temperature. The energy in the water draw is measured and reported as Q_{RES}. For those collectors that have storage outdoors, a test to ascertain the *exponential heat loss coefficient* (L) is performed. This is achieved by filling the outdoor storage tank with 140°F water, letting the system sit for 16 hours at a 71.6°F ambient while a 7.6 mph wind is applied, and then drawing all the water out of the system at the end of 16 hours to determine temperature loss. L is an important number to consider when thinking about purchasing a system with outdoor storage. The higher the value of L, the higher the heat loss from the system. With this the systems test is now completed.

As was mentioned earlier, the solar input can be from one of two sources, a solar simulator or a thermal simulator. A solar simulator used for testing to ASHRAE 95-1981 must meet rigorous specifications. Essentially, it has to present energy to the collector in exactly the same manner as the sun and may consist of an array of highly efficient lamps that move in unison in an arc across the collector as the day progresses. A *thermal* simulator is an in-line electrical resistance heater that heats the systems circulating fluid. To use the thermal simulator, the system being tested must have forced circulation and ASHRAE 93-77 test results for the collectors. The ASHRAE 93-77 test results are used in calculating the thermal energy input to the system. Although the solar simulator input method is preferred, the thermal approach is used by almost all of the forced circulation systems tested because it's less expensive, especially if the supplier's collector has already been through the ASHRAE 93-77 test procedure.

The sequence for a systems test for a solar only and a solar preheat system is the same as for a solar plus supplemental system test except that no Q_{CAP} test is performed.

The rating label for the SRCC systems certification program contains most of the Q values mentioned in this article. However, the most relevant numbers on the label will be Q_{NET}, L and Q_{RES}. The complete set of data tables resulting from a systems test, while perhaps overwhelming for the consumer, provides engineers and designers with an enormous amount of information. In fact, to extend the usefulness and applicability of the systems test, many studies are now underway, investigating methods to predict the performance of the systems in different climates using these test results. Other studies are being conducted to allow manufacturers to substitute equivalent or better components in a system so that a solar supplier does not have to retest every time system design changes are made. ☼

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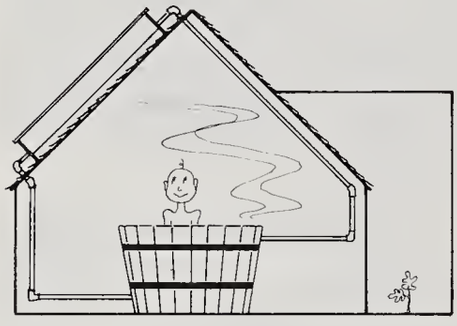
Reliability & Durability in Solar Energy Systems

Huge strides made in design and manufacturing over the past few years haven't diminished a long-standing principle: an experienced, reliable installer is the key to success.



By David Godolphin

If you've been looking into solar space and water heating equipment, you've doubtless grappled with a few terms and concepts over and over again—the collector efficiency curve, cash flow and payback time, cost versus performance.

These are all important considerations, well worth pondering before you buy. But shove them aside for the moment. These concerns just don't matter unless the system will have a long and healthy life.

The reliability and durability of solar equipment profoundly affect its economic value. This can fairly be said of any kind of hardware, of course. But in the case of a solar water heating system, durability is especially critical because it provides no amenity other than heating your water for less money than with other fuels.

It's no secret that many early solar installations failed ("Learning from Experience," *Solar Age,* 11/78). The Department of Housing and Urban Development's Solar Heating and Cooling Demonstration Program, which ran from 1974 into 1979, had its share of short-lived systems. As a technical subcontractor, Dubin-Bloome Associates, West Hartford, Conn., kept tabs on many of the nearly 13,000 systems installed under the HUD program. Robert Sparkes, an engineer with Dubin-Bloome, has fielded many calls for help from system owners. Sparkes talks like a vice-squad cop and has stories to match. His view of solar equipment reliability has been toughened by constant exposure to the worst cases, and his anecdotes are chilling: glycol that cooked under stagnation conditions until it resembled molasses; heat exchangers clogged with rusty sludge from steel piping; controls that turned a system on at night and off at daybreak; wood-backed collectors that slowly incinerated.

Anthony Eden, an engineer with Rockwell International, studied solar materials and reliability while at the Solar Energy Research Institute (SERI). Reminded of the HUD disasters, he says, "Most of the horror stories are attributable to the early part of the learning curve." And Eden speaks for many when he asserts that "active systems are more reliable today than they were four years ago."

But from a vantage point farther along the learning curve observers still see failures—systems that don't last as long as they should, or require costly fixes. Solar researchers in the field of reliability and materials generally trace the problem to system designers and installers rather than the manufacturers. "The systems we have today are very reliable for 20 to 30 years as they come from the manufacturer," says Conrad Vineyard, a SERI cost engineer. The problem, he says, is that "the industry doesn't have enough well-qualified installers."

David Godolphin is an associate editor of Solar Age.

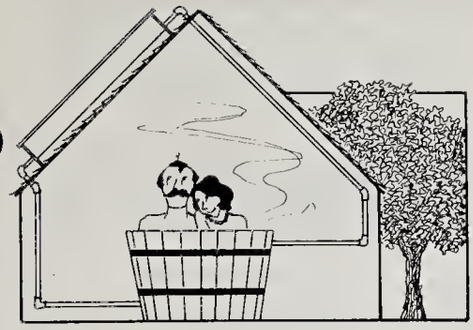
DHR, Inc., a Washington, D.C., consulting firm, has analyzed reliability and maintainability in the solar industry. Their conclusions, contained in *Evaluation of Existing Reliability and Maintainability Programs Affecting Active Solar Heating and Solar Domestic Hot Water Systems,* a comprehensive report for SERI, jibe with Vineyard's claim. One of their findings: much of the knowledge accumulated about do's and don't's of design and installation is not reaching those who need it most—inexperienced designers and installers. As a result, says Richard Silberglitt, a DHR principal and co-author of the report, "We concluded that the major problem is that errors are being repeated.

"There are several good handbooks available," says Silberglitt, "but we had the feeling that handbooks wouldn't really address the problem. The kind of people who go to the trouble of reading handbooks aren't the kind who typically have the problems." Still, one of the simplest steps individuals can take to improve the durability and reliability of systems they buy or install is to read the literature. The vital publications in the field are listed at the end of this article.

Though many factors impinge on the durability of solar equipment, most analysts think that one flawed notion in particular has dogged solar installations. That is the assumption that solar energy systems are just as easy to design and install as most HVAC (heating, ventilating, and air-conditioning) projects. The truth, long acknowledged by solar veterans, is that solar equipment faces much more stress than other mechanical systems in the ordinary house. "Solar applications *are* exposed to tougher conditions than non-solar applications," says Jim Lefferdo, another engineer formerly with SERI's reliability and materials program.

Lefferdo shares Vineyard's concern about the qualifications of solar installers. "We found that if the manufacturer or someone working closely with the manufacturer installed a given manufacturer's system, it would generally perform as advertised. But others who weren't as well informed about the system tended to take shortcuts that led to failure," he says.

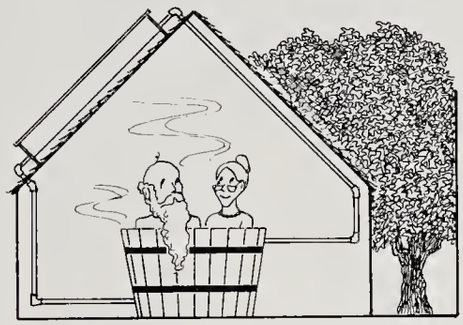
A poor installation shows some ugly physical symptoms that can eat away at performance and, if unchecked, destroy the system. They include corrosion in



tanks, collectors, and pipe runs; frozen waterways; scaling caused by hard water; sealants, glazings, and insulation that deteriorate because they can't take constant sunlight or the 300°F-plus heat of collector stagnation; undersized pumps that burn out early; poorly joined pipes that leak; incompatible metals that attack each other; and valves and vents that don't function as they should because of placement or installation methods.

The causes of and solutions to these problems are well documented. In the northeast, expert site inspectors checked on 170 solar domestic hot water systems as part of a Northeast Solar Energy Center program. Their valuable findings and recommendations are summarized in "The Great, the Good, and the Unacceptable," (see page 29). Sometimes, though, the answers are tucked away in obscure technical reports. Because the solar industry comprises so many businesses, so many of them small, the knowledge needed to install reliable, long-lasting systems doesn't reach everyone it should. The lack of a uniform feedback system that would let many learn from a single mistake has produced a pattern of repeated design and installation errors.

Another contributor to the overall reliability problem may be the solar purchaser. "Outside the solar buffs, there's hardly a homeowner who gives a damn about checking his system," says Robert Sparkes. And, he points out, "a lot of the systems will go into a self-destruct mode if they start to fail and the failure is ignored." "It's true that people generally don't care about maintenance," agrees Anthony Eden. He thinks that the answer may lie with service contracts or conditional warranties, which the homeowner can render void by failing to carry out basic maintenance. Others think the solution could be low-maintenance systems, like those now being developed at SERI and a few of the national laboratories, perhaps combined with low-cost monitoring devices that would make it easier for homeowners to keep an eye on their solar energy systems.



Experts also see reliability and durability improving as a result of the solar industry's trend towards packaged systems and at least the rudiments of system testing. By selling systems rather than individual components, manufacturers make installation easier and assure that major parts of the system will prove durable. "The farther they can take this packaging, the more efficient and reliable the systems will be," says Conrad Vineyard. The DHR report concurs.

Testing complete systems, rather than just collectors, is only beginning, and for the moment it focuses on instantaneous performance and efficiency rather than long-term durability. But it signals that manufacturers are thinking of their products in terms of complete systems. And, as the DHR report puts it, "Activities which emphasize *systems*, from manufacturing through installation and operation, . . . are the activities that are needed to automatically improve R&M [reliability and maintainability] results."

Other evidence suggests that active solar energy systems will be even more reliable and durable four years from now than they are today. Experience is accumulating. Something like a collective body of knowledge is growing as a result. "The installers who did good work have tended to stay in the business," says Anthony Eden. "The ones who made a lot of mistakes have tended to get out of it. Some newcomers are still making errors, but increasingly they're doing their homework before entering the field," Eden says.

Changes in equipment standards and installer training are also likely to help. Installers learning the ropes today benefit from well-grounded educational programs and instructors who, like Robert Sparkes, have spent years on the front lines. Installer licensing, though controversial in some states, is meant to guarantee uniformly sound installations. As long-term data on materials pile up, standards-makers will start to design durability tests.

While all of this progress is taking place, an oft-repeated piece of advice still holds. Find an experienced, reliable installer. Leave no stone unturned in checking references and inspecting previous jobs. If the crew that puts your system in has proved reliable and stayed together for years, the solar equipment will too. ☼

Durability's Canon Law

In its report for the Solar Energy Research Institute, DHR, Inc., noted that much is known about reliability and durability in solar energy systems, but also that few people *know* how much is known or where to find it. The consulting firm reviewed existing publications and singled out some of the best. Most of their choices, along with some very recent and welcome additions to the field, are listed below.

- *Fundamentals of Solar Heating,* by the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), available for $4.50 from Government Printing Office, Superintendent of Documents, Washington, DC 20402. Order No. 061-000-00043-7.
- *Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings,* by Franklin Research Center, available for $5.00 from Superintendent of Documents, Washington, DC 20402. Order No. 023-000-0520-4.
- *The Solar Decision Book of Homes,* by R.H. Montgomery & J. Budnick, available for $25.95 (cloth) or $15.95 (paper) with enclosed check from Order Department, John Wiley & Sons, Eastern Distribution Center, 1 Wiley Dr., Somerset, NJ 08873.
- *Solar Water Heating and Pool Heating Installation and Operation,* by Florida Solar Energy Center (FSEC), available for $8.00 from FSEC, Public Information Office, 300 State Road 401, Cape Canaveral, FL 32920.
- *Installation Standards for One- and Two-Family Dwellings and Multifamily Housing Including Solar,* by SMACNA, available for $20.00 from SMACNA, P.O. Box 70, Merrifield, VA 22116.
- *Solar Heating: A Construction Manual,* by J.A. Adams & P.L. Temple, Total Environmental Action, Inc., available for $25.95 postpaid from SolarVision Publications, Church Hill, Harrisville, NH 03450.
- *The Basics of Solar Air Systems,* by the National Training Fund for the Sheet Metal and Air Conditioning Industry. For ordering information, contact David Harrington at (202) 833-9543.
- *Final Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems,* by Argonne National Laboratory, available for $22.50 from National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161. Order No. ANL/SDP-11.
- *How to Solve Materials and Design Problems in Solar Heating and Cooling,* by D.S. Ward, H.S. Oberoi, & S.D. Weinstein, available for $36.00 (cloth) from Noyes Data Corp., Mill Rd., Park Ridge, NJ 07656.

Solar Hot Water System Ratings: Vest-Pocket Guide to the Labels

DHW System Model	Q_{NET}	Q_{RES}	L	Q_{CAP}	Q_{AUX}	Q_{PAR}	Q_{DL}	No. units/ collectors in system
Integral Collector Storage	**20,900**	4,800	18.85	NA	NA	NA	40,119	2
Thermosiphon	**35,400**	26,500	8.51	21,000	16,500	NA	40,119	3
Pumped Active	**39,300**	43,600	NA	NA	NA	1,621	40,119	2

A new method is now used to test complete solar hot water systems. The standard procedure is officially called ASHRAE 95-1981. The method is a consensus standard arrived at by professionals and technical experts. In addition, two industry trade organizations have announced systems certification programs. Manufacturers joining either the Solar Rating & Certification Corporation (SRCC) or the Air-Conditioning Refrigeration Institute adhere to conditions set by the trade groups when they have their DHW systems tested under the ASHRAE standard method. Members can use the test results along with the trade association logo in their business dealings and, in some states, to qualify equipment for tax credits. Here is an example of the output of the ASHRAE method as applied to three typical DHW systems in the SRCC certification and labeling program, which is the first to begin. The capsule explanations of the terms should help in deciphering the label.

Q_{NET}—A measure of the solar energy delivered by a system under test, in Btu/day. Q_{NET} is generally considered to be the most significant number on the label, which is why it is printed in boldface on the SRCC certificate. If the system uses any auxiliary and parasitic power in the test, Q_{NET} already accounts for it. While the term is reported in Btu/day, Q_{NET} does not predict the actual performance of the solar DHW system in other than the test lab conditions, any more than an EPA mileage rating predicts the actual cost of driving your car.

Q_{RES}—The reserve capacity of the system, in Btu; i.e., the energy left after the full day's water use is drawn off in the test. Q_{RES} does not represent bonus energy collected by the system every day. Rather, it indicates the day-to-day surplus storage capability of the system under the test conditions. Q_{RES} can be a valuable indicator of how sensitive the system is to a real DHW load schedule. The higher the Q_{RES}, the more tolerant the system would be to variations in hot water loads.

L—The exponential heat loss coefficient, in Btu/hr °F; i.e., the rate of heat loss of the system. L is measured only for those systems that have outside storage tanks. Systems with outdoor storage can lose a large portion of the energy they collect to a cold environment at night. Low L values are very important in actual solar DHW installations.

Q_{CAP}—A measure of the energy storage capacity of the auxiliary tank, in Btu. Q_{CAP} is only calculated for those systems that provide their own backup, not those systems that will depend on an existing water heater. The measurement ensures that the system can deliver the full load at the required temperature called for by the test. Whether a Q_{CAP} is listed or a NA (not applicable) appears on the label is a decision made by the manufacturer. For example, a breadbox could have an auxiliary electric heating element in its tank. If the manufacturer chooses to undergo the test with the auxiliary disconnected, there is no Q_{CAP}. A breadbox, or any system, with a Q_{CAP} is by definition a system that includes its own auxiliary heater.

Q_{AUX}—A measure of the backup energy used by the system to deliver the required amount of hot water in the test, in Btu/day. No Q_{AUX} value appears on the label if a system has no auxiliary heating element or has its auxiliary disconnected during the test. To enable these retrofit systems to meet the standard test load, a rating organization will supply the backup, if needed. Remember, Q_{AUX} should not be subtracted from Q_{NET} because this has already been done.

Q_{PAR}—A measure of the energy used to supply power to pumps, controllers, shutters, or trackers needed to operate the system, in Btu/day. Like Q_{AUX}, the parasitic energy is already accounted for in calculating Q_{NET}.

Q_{DL}—The desired load on the solar heating system, in Btu/day. The load chosen for the SRCC program is 40,119 Btu per day, taken in three equal draws. All systems have to supply this amount, either through their own backup or augmented by a backup heater provided by SRCC. This standard load allows the easy comparison of systems. The standard load, however, is not necessarily representative of loads and schedules encountered in actual installations.

No. Units/ Collectors—The number of collectors or complete units supplied by the manufacturer to be tested as a system.

No matter how adroit one becomes in interpreting the rating labels correctly, the cost of the system remains a paramount concern of responsible manufacturers, dealers, and buyers. And the arrival of systems testing hasn't diminished the importance of other factors, such as the reliability and durability of the equipment.

Passive Water Heaters Gaining Ground

A dramatic shift is taking place in the solar hot water market. Even companies that have built solid reputations on active systems are bringing out new passive heaters.

A solar equipment distributor and one of his top dealers met quietly last month in a Sacramento restaurant. Over dinner, the distributor did most of the talking, hard-selling the virtues of a new product he had ready for distribution–an ICS collector, or batch heater. After they'd ordered dessert, the dealer leaned forward across the table and patiently spelled out his position, "Look," he said, "I've spent a lot of time mastering active DHW systems, learning how to sell them, how to install them, and how to service them. Ask me anything you want to know about pumps, or controllers, or sensors, and I can probably give you a pretty good answer. Now, after all that..." and here his voice took on an incredulous, somewhat irritable tone, "...you're asking me to turn around and start selling passive systems?"

Episodes like this are being played out from Los Angeles to Miami as more and more companies introduce thermosiphon and integral collector storage (ICS) systems for the solar domestic hot water market. In California, a bellwether state for the industry, an estimated 38 percent of the 75,000 residential systems sold in 1982 were passive, according to the California Energy Commission. Some private industry analysts estimate that the penetration is now approaching 50 percent of all new installations in California, and the popularity of such systems is rising in other Sun Belt states as well, particularly in New Mexico, Arizona, and Florida.

In a word, the appeal of passive systems lies in their simplicity, which, their advocates claim, makes them much easier to sell and install. Moreover, the argument goes, there's much less maintenance with passive systems, which translates directly into reliability and performance. Finally, and here the theory is not always borne out in reality, passive systems are less expensive than conventional pumped systems.

"Look at the market from a dealer's perspective," suggests Jackson Gouraud, president of Servamatic Solar Systems, a California-based company that has spearheaded the sale of ICS systems and is currently installing over 600 of them a month. "Dealers are in business to make money. When they learn that passive systems are easier to install and nearly maintenance-free, their business sense will steer them in that direction. That's why I think that over the long run passive systems are going to triumph in the marketplace over your complex active systems."

The extent to which passive DHW systems can penetrate the market is an intriguing question, particularly in northern climates where freeze protection is a critical issue. But the fact that so many companies—even ones that have built their reputations on active DHW—are introducing new passive systems is a strong indication that the market is undergoing a meaningful, and perhaps permanent, shift.

Gulf Thermal, a Florida-based firm that has its roots in the active side of the industry, recently introduced the PT-40, a low-profile ICS unit. "We're seeing some definite patterns emerging across the nation," says Griff Carrison, who heads the company's marketing activities. "There's no doubt that passive systems are catching on in the southern California residential market, and to some extent all across the Sun Belt. They can be sold at lower prices than pumped systems and rarely demand service calls, which in turn makes it possible for companies to offer good strong warranties."

Morning Star Manufacturing, another Florida firm that has heretofore made its bread and butter selling collectors for active systems, is also tooling up to produce a new ICS. So too is Fafco, based in Menlo Park, Calif., claiming that its new ICS will match the performance of conventional flat-plate collectors while selling for 30 percent less.

Several new thermosiphon collectors are also making their debut in the American marketplace. Solcoor, which handles Israeli-made Lordan Solar Energy Systems, last month introduced Solar Syphon. And Solar Edwards is gearing up to distribute its Australian-made thermosiphon all across the Sun Belt.

Product development is proceeding in another direction as well: *designing passive DHW systems that can compete in cold-climate markets.*

Despite the fact that the basic technology for ICS and themosiphon collectors has been around for decades, reliable methods to measure their performance are only now being developed. And though the Solar Rating and Certification Corporation (SRCC), the Florida Solar Energy Center, and other industry groups are making important strides in developing reliable test procedures and the means to communicate the results to buyers, most industry observers would concur that the evolution is not complete. Current tests, for example, generally fail to reflect the influence of different climates and hot water use patterns on the performance of collectors and systems.

On the cost side of the equation, buyers intent on doing some comparison shopping at this point in time would find an extraordinary range of prices for ICS and thermosiphon systems, running from about $1000 to $4500. It is worth noting that at the upper end of these price ranges, passive units are costing about the same as—or more than—conventional pumped systems, though they may not be able to deliver comparable performance.

Where prices will finally settle vis-a-vis performance is a subject of lively debate. Some industry observers believe that heated competition, perhaps even a price war, will shape up in the next year or two. Others point to the fact that there are some 28 million houses in the Sun Belt and the level of current market penetration is so low that it will be years before price competition really develops. A third group would argue that few consumers actually shop around or make cost-to-performance evaluations anyway, so the question is moot.

There can be no disagreement, however, that passive solar water heaters are enjoying a rebirth in the United States. Whether or not they will regain their former glory, emerging as the preeminent residential system, remains to be seen.

Marking the resurgence of interest in simple solar water heaters, many thermosiphon and integral collector storage systems are now entering the market. Technical specifications, the results of the system test if available, and the retail list price or installed price are presented for the heaters detailed below. In addition to the manufacturers listed here, several companies offer passive DHW systems that rely on phase-change heat transfer fluids such as Freon™. An article on these special passive heaters will appear in an upcoming issue of *Solar Age*.

Amcor Group, Ltd.
7949 Alabama Ave.
Canoga Park, CA 91304
(213) 992-6592

One of the largest suppliers of solar equipment in Israel and Western Europe, Amcor manufactures both flat-plate collectors and complete thermosiphon water heating systems. More than 150,000 Solon thermosiphon units have been sold worldwide, and total net sales in 1981-82 were $3,610,000. The Solon 120 system can be supplied with an integral electrical backup element in the tank. The system would then qualify as Solar Plus Supplemental under ASHRAE rules but would provide a complete DHW system. The backup element would also function as a convenient, if inefficient, freeze-protection device.

Model: Solon 120, thermosiphon
Gross/Net area: 25.8/22.8 ft^2
Absorber: steel fins/copper risers/black-chrome selective surface
Cover plate: single-glazed tempered-low-iron glass
Frame: extruded anodized aluminum
Insulation: cast polyurethane
Tank: 32-gallon glass-lined steel with cast polyurethane insulation
Freeze protection: drip valve
No. units in system: 1
Systems test: Q_{NET} 20,100 Q_{RES} 750; L 3.66
Price: list $3500-$4500, installed

California Solar Conversion
1345 W. Washington Blvd.
Venice, CA 90291
(213) 392-5766

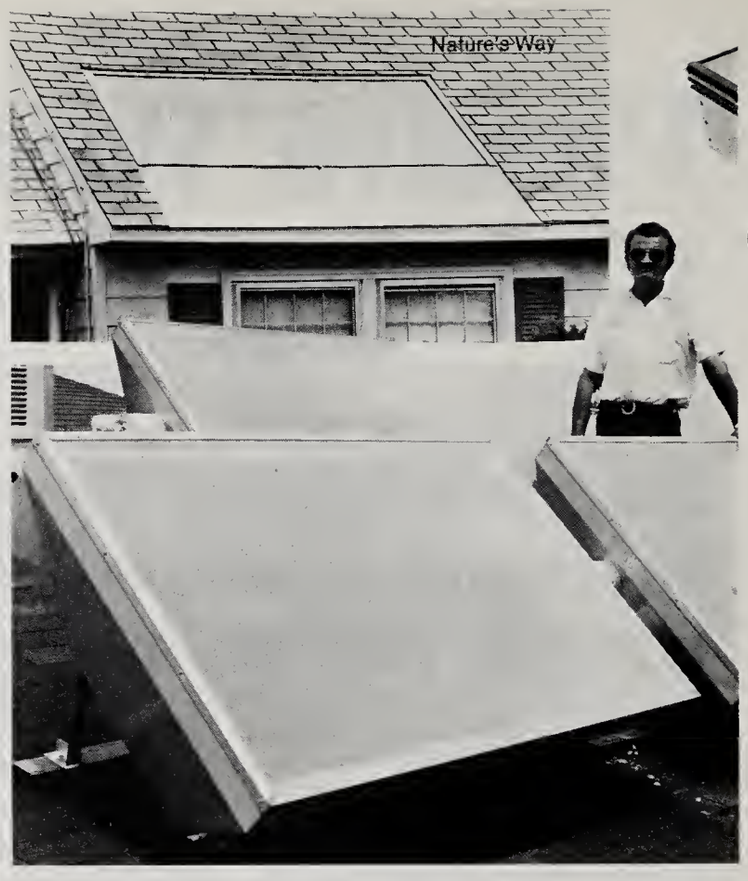
The Salva 1200 is made in France by Salva Eclair, manufacturer of over 15 percent of all the water heaters in France and over 40 percent of French solar water heaters. An integral electrical backup element is available, and a 68-gallon model will be offered soon. California Solar Conversion, which handles importation of the units to California, is actively building a distributor network.

Model: Salva 1200, thermosiphon
Gross/Net area: 8/6.6 ft^2 per panel
Absorber: aluminum fins/copper tubes/black anodized surface
Cover plate: single-glazed tempered low-iron glass
Frame: Enamelled galvanized sheet steel
Insulation: Foamed polyurethane
Tank: 40-gallon cement-lined steel insulated with foamed polyurethane
Freeze protection: drip valve
No. units in system: 1 unit/3 panels
Systems test: Q_{NET} 15,085; Q_{RES} 3345; L 4.03
Price: List $2200-$2500

Conservation Concepts, Inc.
484 Middletown Rd.
Hummelstown, PA 17036
(717) 566-7032

Conservation Concepts has been building passive solar water heaters in the shadow of Three Mile Island since 1980. The current Sundrop unit is designed to be installed as part of or connected to a heated space to allow positive freeze protection. The entire unit can be installed either horizontally or vertically and is also available in kit form for the do-it-yourselfer.

Model: Sundrop, integral collector storage
Gross/Net area: 24.3/23 ft^2
Absorber: Stainless-steel tank with selective surface.
Cover plate: triple glazed/outer tempered low-iron glass/inner dual Teflon
Frame: wood/structural plywood shell
Insulation: polyisocyanurate foam
Tank: 50-gallon 304 stainless steel with selective surface



Freeze protection: connect to heated house or drain during winter
No. units in system: 1
Systems test: no
Price: List $1395

Cornell Energy Inc.
4175 S. Fremont Ave.
Tucson, AZ 85714
(602) 882-4060

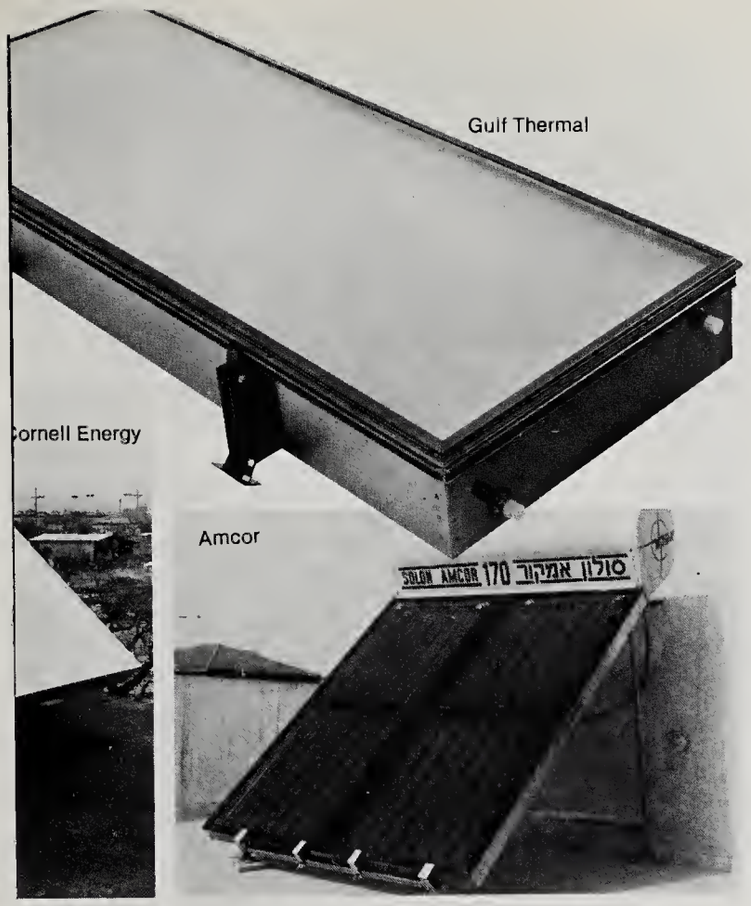
Cornell Energy started manufacturing batch heaters in 1979. By 1982, when the first patent had been granted, it had sold over 1500 units. The latest model, the 360, is one of only a few units covered by a 20-year warranty against freezing, corrosion, and overheating (providing that the unit is installed in accordance with the manufacturer's directions). The classic design makes extensive use of high-technology materials to improve performance.

Model: 360-32, integral collector storage
Gross/Net area: 18.1/17 ft^2
Absorber: steel/selective nickel-foil surface
Cover plate: triple glazed/outer tempered low-iron glass/inner dual fiberglass reinforced acrylic
Frame: fiberglass
Insulation: polyisocyanurate foam
Tank: 32-gallon glass-lined steel with selective surface
Freeze protection: thermal mass/insulation
No. units in system: 2
Systems test: Q_{NET} 19,900; Q_{RES} 5860; L 19.69
Price: List $995/ unit

Entech Marketing, Inc.
PO Box 549
Tualatin, OR 97062
(503) 692-6974

The Sun-Flame passive solar water heater is one of the first ICS systems designed specifically in response to the systems test procedure outlined in the article starting on page 28 of this issue. The selectively coated aluminum absorber is strapped to the storage tank to allow a larger absorber area than usual. When installed between the roof rafters the low-profile unit resembles a skylight and has increased freeze protection.

Model: Sun-Flame, integral collector storage
Gross/Net area: 30.7/24.2 ft^2
Absorber: aluminum plate strapped to tank/black-chrome selective surface
Cover plate: double glazed/outer acrylic/inner Teflon
Frame: aluminum
Insulation: polyisocyanurate foam/fiberglass
Tank: 36-gallon glass-lined steel
Freeze protection: drain during freezing periods



No. units in system: 2
Stytems test: Q_{NET} 26,400; Q_{RES} 10,300; L 15.09
Price: List $1100-$1400/unit

Environment One Corp.
2773 Balltown Rd.
Schenectady, NY 12309
(518) 346-6161

The E|One thermosiphon unit represents the first foray into the solar market by a northern company primarily involved with the manufacturing and marketing of electrical and electronic products and systems for controlling environmental pollution. The highly engineered E|One is designed for either ground or roof mounting and uses a horizontal collector for a low profile.

Model: E|One Thermosyphon
Gross/Net area: 42.3/21.5 ft^2 (gross includes footprint of tank)
Absorber: copper fins, risers, headers/semi-selective black surface
Cover plate: single glazed/low-iron tempered glass
Frame: fiberglass/aluminum
Insulation: fiberglass/polyisocyanurate foam
Tank: 40-gallon glass-lined steel with polyisocyanurate insulation
Freeze protection: drip valve
No. units in system: 1
Systems test: no
Price: List $1595

Gulf Thermal Corp.
PO Box 1273
Sarasota, FL 33578
(813) 957-0106

The ProgressivTube trade name for the PT-40 is descriptive of the design of the horizontal absorber/storage tanks. The cold water enters the unit at the bottom, feeding into the first tank. The next three tanks are connected in series, providing good stratification as the water in the upper tanks gets progressively hotter. The feed to the house is off the top using the hottest water first. When properly installed, Gulf Thermal offers a 20-year warranty against freezing.

Model: PT-40, integral collector storage
Gross/Net area: 19.5/17.4 ft^2 per unit
Absorber: stainless-steel tanks with selective paint
Cover plate: triple glazed/outer tempered low-iron glass/inner dual Teflon
Frame: extruded aluminum
Insulation: polyisocyanurate/unbonded borosilicate
Tank: four 304 stainless-steel tanks connected in series/total volume 38.3 gallons per unit
Freeze protection: thermal mass/drain during freezing weather
No. units in system: 2
Systems test: Q_{NET} 24,600; Q_{RES} 12,200; L26.83
Price: Dealer quote $3500-$4500, installed

Intersolar
9505 Bamboo Road
Houston,TX 77041
(713) 462-6111

Intersolar , with offices in Houston, London, Zurich Sydney, and Durban, serves as the marketing firm for a consortium of several companies manufacturing solar equipment. In addition to the thermosiphon unit listed, Intersolar will be selling a 30-gallon batch heater, a larger thermosiphon unit, and a line of freeze-tolerant stainless-steel collectors. The company is actively looking for American distributors of its products.

Model: Solarval Thermosyphon
Gross/Net area: 15.3/9.8 ft^2 (gross includes tank footprint)
Absorber: 444 18 Cr 2 Mo stainless steel/flat-black or selective surface
Cover plate: polycarbonate or low-iron tempered glass
Frame: aluminum
Insulation: 1" fiberglass
Tank: 19-gallon stainless steel/fiberglass insulation/FRP cover
Freeze protection: absorber design is inherently freeze-tolerant
No. units in system: 1
Systems test: in progress
Price: List $480-$600

King Energy Systems, Inc.
1961 McGaw
Irvine, CA 92714
(714) 754-5783

King Energy may be the largest domestic manufacturer of batch heaters, It sells the Sunchief 6000 under its own label, also manufactures the Sun Flow 600 RD for Servamatic Corporation, and has a line of flat-plate collectors. The 6000 is double glazed with polycarbonate and uses a fixed stainless-steel reflector below the horizontally mounted tanks to concentrate sunlight on the absorber.

Model: 6000, integral collector storage
Gross/Net area: 13.19/12 ft^2
Absorber: stainless-steel tank/flat-black paint
Cover plate: double glazed/dual polycarbonate
Frame: stainless steel
Insulation: air
Tank: 20-gallon 304 L stainless steel
Freeze protection: drain in freezing weather
No. units in system: 3
Systems test: Q_{NET} 20,400; Q_{RES} 5400; L 28.72
Price: Dealer quote $3800–$4600, installed (includes other conservation measures)

Nature's Way Energy Systems
PO Route 8
Old Homestead Highway
Keene, NH 03431
(603) 352-1186

The Enhanced Batch Module is designed to be built into the house, usually as part of the attic, eliminating freeze problems. The outer layer of glazing then becomes the weather surface of the roof. The stainless-steel tank is covered at night by insulated shutters that greatly reduce heat loss and can be operated manually or automatically.

Model: Enhanced Batch Module
Gross/Net area: 24.3/22.6 ft^2
Absorber: stainless-steel tank/sunsponge selective surface
Cover plate: double glazed/low-iron glass
Frame: wood/aluminum/moveable insulated shutters
Insulation: polyisocanurate foam
Tank: 40-gallon stainless steel
Freeze protection: interior to house with increased night insulation
No. units in system: 1
Systems test: no
Price: List $1322

Prime Energy Products Inc.
7669 Washington Ave. S
Edina, MN 55435
(612) 944-9300

Prime Energy is a Minnesota company that markets its batch heater locally primarily for use in summer homes or hunting cottages. The Concentrator is available in either horizontal or vertical models. In addition, Prime Energy will soon

distribute the Thermomax phase-change passive heater, manufactured in Northern Ireland. This heater will be able to use either water or a fluorocarbon as the heat transfer fluid.

Model: Concentrator, integral collector storage
Gross/Net area: 26/20.25 ft²
Absorber: steel tank with semi-selective flat-black paint
Cover plate: triple glazed/outer tempered glass/inner dual Teflon
Frame: aluminum
Insulation polyisocyanurate foam
Tank: 30-gallon glass-lined steel
Freeze protection: thermal mass/insulation/drain during freezing weather
No. units in system: 1
Systems test: no
Price: List $875

Servamatic Solar Systems
1641 Challenge Dr.
Concord CA 94520
(415) 680-8853

Servamatic stresses that when it sells the Sun Flow 600 RD it is selling a system. The purchase price includes various other conservation measures, such as reinsulating the existing water heater and hot water pipes. Servamatic has sold over 18,000 batch heaters and is presently installing about 600 a month.

Model: Sun Flow 600 RD, integral collector storage
Gross/Net area: 27.2/24.8 ft²
Absorber: 304 L stainless-steel tank/non-selective black paint
Cover plate: double glazed/outer DR-plex acrylic/inner polycarbonate
Frame: plastic
Insulation: air
Tank: 25-gallon stainless steel
Freeze protection: drain during freezing weather
No. units in system: 2
Systems test: Q_{NET} 20,900; Q_{RES} 4800; L 18.85
Price: List $3800-$4400, installed (includes other conservation measures)

Sharpe Solar Systems
4300 Easton Drive, Suite #4
Bakersfield, CA 93309
(805) 325-4220

Sharpe is a small company that builds and markets the Magic Box batch heater in and around Bakersfield, Calif. The Magic Box is one of the few ICS units that uses FRP (Filon™ in this case) as an outer glazing material. The heater uses two tanks plumbed in series with flat black on the first tank and a selective surface on the second to help reduce heat loss.

Model: Magic Box, integral collector storage
Gross/Net area: 32/26.5 ft²
Absorber: steel tanks with flat-black paint on first/selective surface on second
Cover plate: double glazed/outer FRP/inner Teflon
Frame: aluminum
Insulation: polyurethane foam
Tank: dual 30-gallon glass-lined steel
Freeze protection: drain during freezing weather
No. units in system: 1
Systems test: in progress
Price: List $1595

Solahart USA
3560 Dunhill St.
San Diego, CA 92121
(619) 452-5805

Solahart is an Australian-based company that has been producing thermosiphon units since 1953, although the appearance of its new unit bears little resemblance to the earlier models. Solahart is the only manufacturer at present to have submitted its thermosiphon unit for testing as a Solar Plus Supplemental using an integral electrical element to provide backup auxiliary heating. A new model, (which has not completed the system test), the 300LJ, uses a tank-within-a-tank for freeze protection. The collector fluid (propylene glycol) is circulated around the outside of the storage tank and does not mix with the domestic water supply.

Model: 80 GE, thermosiphon
Gross/Net area: 21.3/20.1 ft² per panel
Absorber: aluminum panel/copper tubes/flat-black paint surface
Cover plate: single glazed/tempered-low-iron glass
Frame: aluminum
Insulation: fiberglass/polystyrene
Tank: 80-gallon glass-lined steel/polyurethane insulation/aluminum cover
Freeze protection: integral auxiliary heating element
No. units in system: 1 unit/3 panels
Systems test: Q_{NET} 35,400; Q_{RES} 26,500; L 8.51; Q_{CAP} 21,000; Q_{AUX} 16,500
Price: List $4400-$4500, installed

Solar Components Corp.
PO Box 237
Manchester, NH 03105
(603) 668-8186

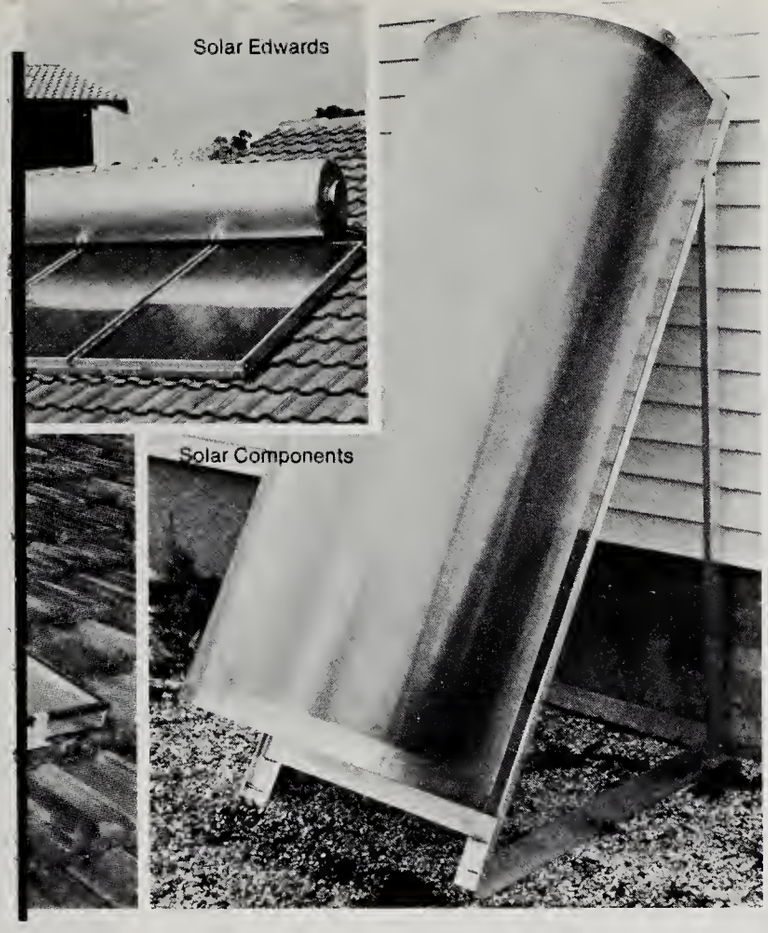
Solar Components, a longtime mail-order supplier of solar products, manufactures Sunlite, a proprietary fiberglass-reinforced plastic glazing material. Recently it has introduced a batch heater using two 30-gallon tanks in series and double glazed with Sunlite. The manufacturer says that the heaters have survived three New Hampshire winters without freezing. Energy production in winter is low and further reduced when the energy used by the pad-heater freeze-protection device is taken into account.

Model: Sunlite Solar Water Heater, integral collector storage
Gross/Net area: 14.9/10 ft² (net is area of absorber tanks)
Absorber: steel tanks with flat-black paint surface
Cover plate: double glazed/dual FRP
Frame: aluminum
Insulation: polyisocyanurate foam
Tank: dual 30-gallon glass-lined steel tanks with flat-black paint
Freeze protection: optional electric pad heaters
No. units in system: 1
Systems test: no
Price: List $999.00

Solar Edwards, Inc.,
7636 Miramar Rd., Suite 1400
San Diego, CA 92126
(619) 695-0888

Solar Edwards is a rival of Solahart in Australia but a relative newcomer to the American scene. It is one of the latest recipients of the Australian Design Award for hot water systems (May 1982) for models L305 and L440. The L305, which underwent systems testing as a solar preheat unit, could equally well have been submitted as a Solar Plus Supplemental unit using the optional integral electrical backup heating element.

Model: L305, thermosiphon
Gross/Net area: 21.1/20.1 ft² per panel
Absorber: aluminum fin/copper tubes/flat-black paint



surface
Cover plate: single-glazed low-iron tempered glass
Frame: zinc-aluminum coated steel
Insulation: fiberglass
Tank: 80.7-gallon stainless steel/polyurethane insulation/aluminum cover
Freeze protection: optional integral auxiliary heating element
No. units in system: 1 unit/2 panels
Systems test: Q_{NET} 25,000; Q_{RES} 17,200; L 7.92
Price: List $3000-$4000, installed

Solcoor Incorporated
849 S. Broadway, Suite 208
Los Angeles, CA 90014
(213) 622-4181

Solcoor, Inc., is the United States marketing arm for Lordan, a large Israeli manufacturing firm. Lordan's Thermosyphone, which is presently undergoing systems testing at the DSET Laboratories in Arizona, is widely sold in Israel and uses the LSC-D collector with pressure-injected isocyanurate insulation. Over 70,000 units have been installed worldwide.

Model: Lordan Solar Syphon, thermosiphon
Gross/Net area: 21.9/20.8 ft²
Absorber: vertical aluminum fins/copper tubes/flat-black surface
Cover plate: single glazed/tempered low-iron glass
Frame: galvanized steel/black acrylic coating
Insulation: injection-molded isocyanurate
Tank: 28-gallon glass-lined steel with isocyanurate insulation/galvanized steel cover
Freeze protection: drip valve if required
Systems test: in progress
Price: List $800-$900

Sunloop Corporation
4208 N. Freeway Blvd., #4
Sacramento, CA 95834
(916) 924-7244

The Hot Stuff is a twin-tank batch heater. The tanks are connected in series to increase the stratification of hot water. In new construction the galvanized frame can be recessed into the roof between the rafters, giving the clean appearance of a skylight and providing increased freeze protection. The triple glazing incorporates a layer of infrared reflective film (Heat Mirror™) for increased heat retention.

Model: Hot Stuff, integral collector storage
Gross/Net area: 27.8/24.3 ft²
Absorber: steel tank/black-chrome selective surface
Cover plate: triple glazed/outer tempered glass/middle Heat Mirror™/inner low-iron glass
Frame: Painted galvanized steel
Insulation: polyurethane
Tank: twin 30-gallon glass-lined steel tanks with black-chrome selective surface/total volume 60 gallons
Freeze protection: drain during freezing weather
No. units in system: 1
Systems test: in progress
Price: List $2000

Sunwizard Inc.
1424 West 259th St.
Harbor City, CA 90710
(213) 539-8590

The Sunwizard is one of the most unusual looking batch heaters on sale today. Commonly placed vertically on a patio, the unit has a cylindrical glazing completely surrounding the 120-gallon tank. An optional auxiliary electrical element can be installed. The Sunwizard uses a silica gel and activated-charcoal solar-regenerated dessicator to prevent condensation inside the unit.

Model: Sunwizard 120
Gross/Net area: 47/38 ft² (net is absorber tank)
Absorber: glass-lined steel/black-nickel selective surface
Cover plate: single glazed/acrylic
Frame: plastic/wood
Insulation: air space
Tank: 120-gallon glass-lined steel with selective surface
Freeze protection: drain in freezing weather
No. units in system: 1
Systems test: Q_{NET} 11,500; Q_{RES} 6100; L 23.92
Price: List $1100-$1300

TEF Manufacturing
1550 N. Clark
Fresno, CA 93703
(209) 441-1833

TEF, in the solar energy field since 1974, has just moved into the batch heater market with the introduction of the SunRunner—an innovative ICS unit. The SunRunner uses a 12-volt motorized insulated shutter to reduce heat loss from the tank whenever there is no useful solar energy to collect. The shutter opens when a temperature probe in the front cavity of the unit is hotter than 110°F. The shutter closes, fully surrounding the absorber/storage tank, when the probe temperature drops to 100°F.

Model: SunRunner, integral collector storage
Gross/Net area: 30/22.7 ft²
Absorber: single glazed/tempered-low-iron glass
Frame: zinc-plated steel/enamel coating
Insulation: polyisocyanurate
Tank: 40-gallon glass-lined with selective surface
Freeze protection: automatic movable insulated shutter
No. units in system: 1
Systems test: in progress
Price: List $1349-$1499

Western Solar Tech Inc.
4221 Luther St.
PO Box 20121
Riverside, CA 92506
(714) 683-5290

While Western Solar Tech is a relatively small company, its Monterey ICS is a classic, high-tech batch heater using a stainless-steel tank, selective foil surface, and a computer-designed reflector to augment the radiation striking the tank. A chart, shipped with the legs for the heater, gives the precise leg lengths required for correct installation on any roof. Two or three units are usually installed in series for residential applications.

Model: Monterey, integral collector storage
Gross/Net area: 13.5/10.8 ft²
Absorber: stainless-steel tank with selective black-chrome foil surface
Cover plate: double glazed/dual tempered-low-iron glass
Frame: steel/fiberglass
Insulation: fiberglass
Tank: 23-gallon 304 stainless steel with black-chrome surface
Freeze protection: drain unit during freezing weather
No. units in system: 3
Systems test: Q_{NET} 19,500; Q_{RES} 10,200; L 16.33
Price: List $3700 for three-unit system, installed

Keep It Simple, Cool, and Cheap

These three cardinal rules emerge from five years of field experience with solar heating, cooling, and hot water installations. Together, they point the way to great system performance.

By C.J. Kelly

You've decided on solar heating, cooling, or hot water for your building. The success of the project depends on you. You've read the glowing reports of profitable solar projects, but you've also seen gloating accounts of disasters. Many of these failures were designed by people who should have known what to do. How can you ensure that your system does not end up one of the casualties? Hasn't anyone assembled all the lessons learned from both the successes and the failures? Yes. The National Solar Data Network has analyzed instrumented data from well over 100 installations throughout the United States since 1977. In addition, network personnel have reviewed the designs at hundreds of other sites, visiting many of them, to see if they were suitable for instrumenting. This article will give you some important suggestions based on this experience.

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Greig Cranna

Sunworks

Thomason Solar Homes, Inc.

Heating and cooling with reflector enhanced collectors, the Lutz-Sotire Building, Stamford, Conn. (above). "SOLARIS" by Cates Construction Co., one of about 15 "SOLARIS"-heated and cooled homes in the Summerfield subdivision (right). Residential space heating and domestic hot water in Westbrook, Conn. (below).

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What follows is not intended to be a design manual. There are plenty of good texts and handbooks available for that. Nor will this article give you a substitute for careful design. What it does provide is direction for you if you are confronted with alternatives. If you are a designer deciding which possible path to take or a buyer given several options, you can benefit from this advice. Most of what I have to say is not new. Even though the principles of good solar heating and cooling design are handy, they were obviously not well understood by the people who designed, selected, or built many of the projects I have seen.

We have condensed the most important things we learned into three basic principles to guide you when you need to select a solar design. They are: keep it simple, keep it cool, keep it cheap. If they are kept in mind during the design selection, you will avoid the most common problems.

Keep it simple

A solar heating or cooling installation is a fairly complex project to begin with. It almost always contains a conventional system as a backup. Over and above that are the solar-specific piping or ductwork, a controller, storage, pumps, fans, valves, dampers, etc. All of these increase the system cost, the risk of design errors, performance shortfalls, and reliability problems. Keep the number and complexity of these components down even if it means choosing a dull, pedestrian, solar design.

The greatest danger in complex designs is excess parasitic energy. Parasitic energy refers to the energy required to operate the solar components of the system. Since this energy is almost always electricity, its use directly reduces the savings gained from the solar energy system. As the complexity increases, the number and size of pumps, fans, motorized valves, and dampers also grows. I have seen very complex systems use half as much electrical energy as the solar energy delivered. I agree innovation makes progress. Unfortunately, it can also make failure when it breeds complexity. Your best chance for success for yourself or your client is to stick with simple, straightforward, textbook designs.

Keep it cool

I use the word *cool* in a relative sense. Certainly, solar energy must be at least warm to be useful, but many systems are set so that solar isn't used until it is relatively hot. Energy isn't drawn from storage, sometimes collectors aren't even turned on, until these high temperatures are achieved. This is usually done so that the delivery device—the furnace, heater, or whatever—can operate at its most efficient level. This is a mistake. High temperature solar energy will be available during only part of the good days. You must make use of the lower temperature energy to save enough auxiliary energy to justify the cost of the system. Use solar energy at the lowest temperature the delivery system will accept and still work efficiently, that is, will not require excessive operating energy (parasitics). In fact, you should look for delivery devices that work well at low temperatures.

This is a good place to note that this principle must be applied carefully so as

Table 1: Solar space heating/seasonal performance of an office building in Lynchburg, Va.

	Comparison with and without solar-assisted heat pump	
	1978-79 Without Heat Pump	1979-80 With Heat Pump
Solar fraction	33%	74%
Energy saved (natural gas)	24.05 MMBtu	41.19 MMBtu
Energy expense (electricity)	4.51 MMBtu	9.83 MMBtu
Net savings* (dollars)	$52.00	$58.00

*Based on winter 1980 fuel cost of $0.05 kWh of electricity and $5.00/1000 ft³ of natural gas.

Table 2: Typical economic factors for sites in the National Solar Data Network

System Type	Range of Cost Per Collector Area $/ft²	Yearly Range of Energy Saved Per Collector Area Btu/ft²	Range of Return on Investment After Inflation %
Hot water only	40 to 60	190,000 to 290,000	15 to 18
Heating or Hot Water and Heating	30 to 50	70,000 to 180,000	2 to 20

not to jeopardize the other two. For example, one way to lower the solar utilization temperature is to use a heat pump to deliver solar energy for heating the building. The heat pump will take solar energy at quite low temperatures and deliver it at high heating temperatures fairly efficiently. This splendidly satisfies the keep-it-cool principle, but certainly does not keep it simple or cheap. The heat pump is more complex and costly than say, a hot-air duct heat exchanger. It will require more complex controls, be harder to design, increase operating costs, and probably decrease reliability. Will the improved performance justify the additional cost and risk? Let's see.

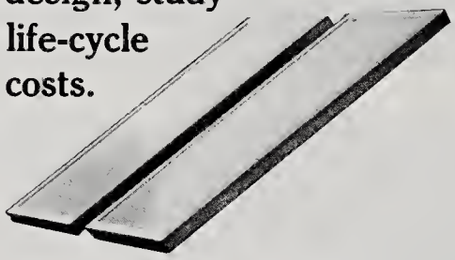
Table 1 is a performance comparison, taken from the data network, of a solar space heating system installed in a small office building and warehouse in Virginia. During the 1978-79 heating season, the performance of the system had been middling. The heating solar fraction was 33 percent. A solar-driven heat pump was installed, thereby lowering the solar utilization temperature from 105°F to 55°F. As expected, the solar fraction increased dramatically to 74 percent and the amount of natural gas used for backup decreased. But the electrical expense required to operate the solar delivery system also increased. The net increase in monetary savings using recent energy costs for the Lynchburg location was only $6.00. The savings did not justify the purchase of a heat pump.

A solar-assisted heat pump might have proven cost-effective under different physical and economic conditions. The point here is that when a design selection puts these basic principles in direct conflict with each other, it should sound a warning. You had best have a thorough engineering and economic justification for that choice.

Keep it cheap

This may seem obvious, but data from the solar network show that it is very often violated, destroying the possibility of any real gain from the solar installation. Attention to the cost of a system usually centers on the collector array since it is generally the most expensive subsystem. The cost of a solar energy system is often quoted in dollars per square foot of collector. The larger the array, the greater the square foot area to divide into the total system cost. However, a larger collector array may not be as cost-effective as a smaller one. Keeping the size of the array down is as important as keeping the cost per square foot low. Economies can of course be made in other parts of the system, and the total cost should be kept in mind. One way to do this is to determine the conventional energy saved per square foot of collector area.

Collector cost and energy saved are only rough indicators of economic merit. Before selecting a design, study life-cycle costs.



Collector cost and energy saved are only rough indicators of economic merit. Before a design is selected, a life-cycle cost study must be done. Several life-cycle cost indicators are in use, such as payback period. I prefer the annual return on investment (ROI) after inflation. A range of figures for the data network sites has been calculated by Thomas King of Mueller Associates, Inc., of Baltimore. Some of these figures are shown in Table 2.

A common mistake that causes unnecessary cost is going for a very large solar fraction. Large solar fractions usually entail large collector arrays. They may also require expensive collectors, controllers, or other equipment. It is better to accept a smaller solar fraction in order to achieve an economical design. Concentrate on energy savings compared to the cost of the system. The solar fraction is only a design tool. In commercial or industrial applications with large loads, a small solar fraction of even 10 percent to 15 percent might result in impressive savings. The cost of the conventional fuel being replaced can also have considerable impact.

Table 2 has no figures for cooling applications although the network has several representative active solar cooling systems. Not one has shown significant energy savings when compared to a conventional electric air conditioner. Most have been net energy losers. The only commercially feasible active solar cooling strategy at this time involves using absorption-type air conditioners. These machines were originally developed to use fossil energy to heat a refrigerant mixture and they have been adapted to use solar energy as the heat source. Unfortunately, it is very difficult to adhere to the three principles with this type of design. The absorption air conditioners often require temperatures above 180°F to operate efficiently, thus making it difficult to keep it cool. The absorption chiller is usually augmented by a conventional vapor cycle electric chiller. A modern vapor cycle chiller can operate at a coefficient of performance (COP) of up to 4.5, whereas the solar driven absorption machine operates at a COP of 0.6 to 0.7. High-performance collectors, sophisticated control systems, additional storage, and other strategies are required to overcome the high temperature requirements and low COP. All of this makes it next to impossible to keep it simple and cheap. This is not to say that a successful active solar cooling design is not possible, but a successful design has not been demonstrated in the network. Unless you are prepared to take some risk, I would not recommend an active cooling system at this time, except possibly to replace or augment an existing fossil-fuel-fired system.

While the three basic principles summarize the most important of the lessons learned in the network, anyone about to make a solar design selection should consider many other points. The following is a guide to successful solar design. Each item is short and easy to remember.

Concentrate on controls: The control system is perhaps the most difficult part of the system to design. It demands competent, thoughtful planning. It is here you can make the simple, cool, cheap system work for you. Here you can ensure that solar is used at the lowest temperature feasible, that simple, inexpensive components can be made to perform. Controls are the brains of the system, and it takes brains to design it.

Minimize losses: Just because the solar energy is free doesn't mean it shouldn't be conserved. You must deliver enough solar to the load to justify your capital investment. Insulation is a must on all solar piping and ducting. While uncontrolled losses into the heating space may contribute useful energy, they can also cause uneven

distribution and increase the cooling load. Systems using air collectors are particularly susceptible to uncontrolled losses caused by leakage from ducts. Sealed ducts are preferred. Leaky dampers are also a major cause of losses in these systems. Some do not close tightly or don't remain tight after the initial adjustment. Duct or damper leaks can increase building infiltration also. This can be minimized by putting the collector loop fan in the collector-to-storage leg. In air or liquid systems, outdoor storage should be very well insulated, and the insulation protected from moisture, especially ground water.

Control corrosion: Many liquid-based solar designs leave portions of the liquid loops open to the atmosphere. This makes them more susceptible to corrosion than conventional heating and cooling designs. Some designs use antifreeze for protection of the collector components. This may make periodic and expensive replacement of the fluid necessary as corrosion inhibitors deteriorate. Dissimilar metals, such as copper and steel, in the same loop should be avoided unless galvanic protection is provided.

Provide monitoring: Most installations in the National Solar Data Network have experienced problems, especially during start up, which could not have been discovered without instrumentation. Investing a few hundred dollars in some basic monitoring equipment can save thousands in damage or wasted energy.

Minimize maintenance: The solar energy system will be more complex than a conventional heating or cooling plant, yet users are not likely to spend much more effort maintaining and operating it. This is especially true in a residential application. Keep maintenance and operating requirements low.

Analyze the economics. Economics are hard to keep in mind while immersed in the intricacies of technical design. Yet, the bottom line is the dollar saving and whether or not it justifies the cost of the system. Always demand a thorough economic analysis based on realistic projections of fuel cost and other factors plus a conservative estimate of thermal performance.

Select collectors carefully: Collectors are usually the biggest subsystem expense for the installation. Be sure the size of the array is the smallest that will do the job satisfactorily and that the type and model collector selected is the most economical. This may seem obvious but it is often forgotten. Expensive tracking collectors have been used where cheaper flat-plate designs would have sufficed.

Avoid shading: Most people (but apparently not all) are aware of the dangers of collector shading by trees or adjacent buildings, but collector self-shading is frequently found. That is, where collectors are arranged in rows the forward rows can block part of the sun from the after rows. A typical error is to check for self-shading for the noonday sun at the winter solstice. This may allow for considerable shading during the morning and afternoon hours of the short winter day.

Expect less: Experience in the solar data network indicates that collector arrays perform less well than the efficiency curves given by the manufacturers would indicate. This is because the manufacturers' curves are taken under carefully controlled laboratory conditions on a single collector panel. In cases where the network has been able to accurately measure the energy losses from storage tanks or other components, the insulation appears to be much less effective than expected. The only guidelines that I can give are to design conservatively, pay particular attention to the flow in all parts of the array, and guard against thermal short circuits around insulation such as metal and pipe supports.

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Space heating and domestic hot water at Cheshire Elderly Housing, Cheshire, Conn. Capone Construction, contractor.

Favor stratification: Temperature stratification in storage tanks or bins is almost always beneficial. It presents one way to resolve the conflict between the low temperatures favored by the solar end and the high temperatures required at the load end. Simply feed the collector array from the cool bottom of the stratified tank or box and accommodate the load from the hot top. Some designers have gone so far as to install pumps to keep the storage tank fully mixed. Although design calculations may be done assuming a fully mixed tank for simplicity, the mixing should not be forced in reality. In fact, it is often advisable to install baffles or other devices in storage tanks to encourage stratification. Actual versus theoretical performance results were compared for a passive, thermosiphon solar hot water system in Honolulu, Hawaii. Since the flow in the actual thermosiphon array was much less than the laboratory test conditions, the system performance should have been degraded. However, the benefits of full stratification in the storage tank overcame this and the actual performance was virtually identical to the simulated one.

Bypass storage: A percentage of any energy put into storage will be lost. No one has yet invented the perfect insulation. Therefore, when there is a demand at the load end of the system and there is useful solar energy available from the collectors it should be provided directly. That is, there should be some means for bypassing solar energy around or through storage and delivering it directly to the space.

Exclude auxiliary: The conventional auxiliary energy is what you are trying to conserve. It is almost always available on demand. There is seldom any reason to put auxiliary energy in the solar storage device where some of it will be needlessly lost. Avoid designs which allow auxiliary energy to go to storage unless they are strongly justified by other considerations (load management, off-peak electricity, for instance).

Size carefully: There may be a temptation to use a storage device that is available—in a retrofit, for instance. Don't give in. If a storage device is of the wrong size, it can seriously affect performance. Using an available storage device may be false economy. Any solar design textbook will describe how to select the proper storage size.

Accommodate losses: Designing for the peak domestic hot water demand is standard practice. This is important for fast recovery. But an essential in solar hot water system design is the loss from the water heater tank and associated piping. This is especially true if there is a recirculation loop. In retrofit applications in large residential complexes, the losses from uninsulated recirculation loops often exceed the energy delivered to users. Design the system so that solar energy can make up a portion of the recirculation losses in such cases. As a conservation measure, you might consider whether a recirculation loop is really necessary.

Design for morning. Designs for residential hot water applications should expect the peak load in the morning. Some design programs are based on peak hot water loads in the afternoon, but a study of 202 living units in the NSDN showed that almost 66 percent of the daily demand occurred between 6:30 and 9:30 a.m.

Should you combine?: Consider carefully any combination of a hot water system with another application such as space heating. Such designs can be successful, although many have not been. The system must be sized for the heating load.

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Will the operating energy required to use the system over the summer months detract from the energy savings? Should part or all of the system be shut down when heating is not needed? Will losses from the system add appreciably to the cooling load?

Err on the low side: Calculating the load is very difficult, especially for a new building. Because of this uncertainty, it is generally necessary to err on the high side when selecting a conventional heating system so that peak heating needs will be met. *This is not true for solar heating applications.* Remember to keep it cheap. To select a successful design it is more important not to oversize the solar components, particularly the collector array. It is better to consider that the predicted load may be too high when sizing the solar system.

Off in summer: If the system has a heating application only, be sure it can be turned off during the cooling season. This will save operating energy and avoid adding to the cooling load. However, make sure the collectors are protected from possible stagnation damage while the system is off.

That is all the help I can provide here. You can find out more about the lessons learned from two reports: *Solar Design and Installation Experience: An Overview of Results from the National Solar Data Network,* SOLAR/0009-81/73 and *Guide to Effective Solar Heating and Cooling Practice,* SOLAR/0091-81/00 available free of charge from the U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, Tenn. 37830. The first document is the more technical. ☼

Bibliography

The following books and one magazine article are some of the better solar design texts. Most are very technical, being written for engineers and designers. The first listed under each of the two categories is a good introduction.

Active Systems

Solar Heating Design by the f-Chart Method, W. Beckman, S. Klein and J. Duffie, John Wiley and Sons 1977

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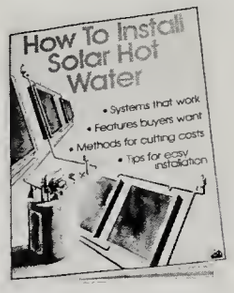
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How To Size Up Solar Air Systems

An active air system that works well is properly engineered and follows established HVAC practices. This involves much more than choosing a high-performance solar collector.

By Vic Reno

Working with active solar air systems requires a level of skill and expertise in residential heating once found only among commercial contractors. The air system contains collectors, storage, controls, dampers, ducts, fans, and accessories, such as hot water heat exchangers, filters, vents, and monitoring devices. The system may have four or more modes of operation, in contrast to conventional residential heating systems with a single mode.

Many active air systems work very well. Others fail miserably. Some are plagued with problems that time, money, and experience may or may not solve. Most of these problems and failures can be traced to poorly designed or improperly sized components, and incorrect installation (failure to follow directions). The good systems work because they are properly engineered, well thought out, and follow established HVAC practices and procedures.

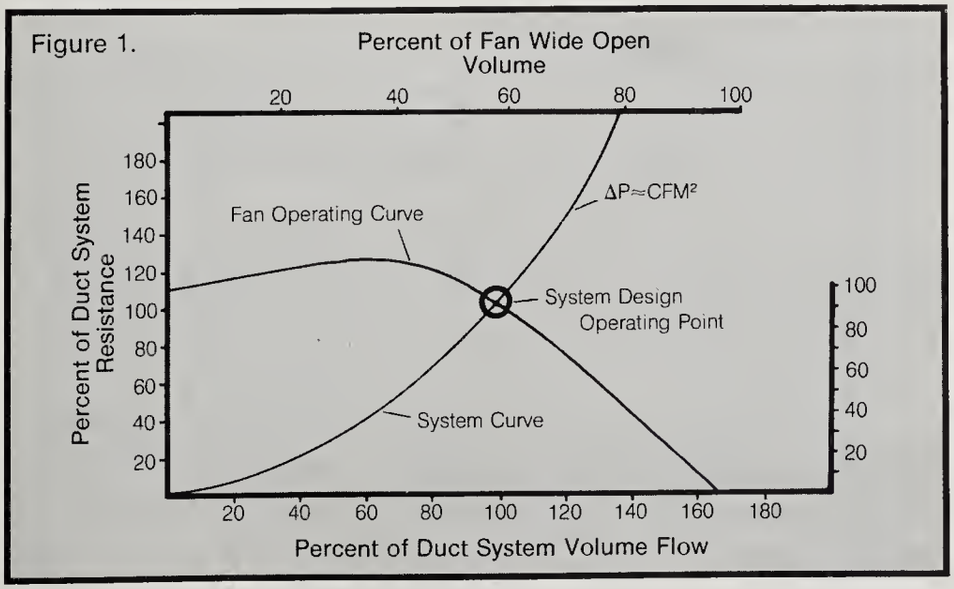
A large house (3,500 square feet) in southern Maine gets about half its heat and 60 percent of its hot water from solar energy. It uses the active, warm air CSI/Solar® System from Contemporary Systems, Inc. CSI/Solar combines features of site-built and manufactured systems, resulting in collectors that are part of the roof structure.

Fans

To operate properly, air-moving systems depend on fan engineering. Centrifugal fans can have blades with forward or backward curves, or straight blades. Axial fans also have different characteristics. Choosing a fan carefully helps to ensure the economical and dependable operation of the solar air system.

The forward-curved, belt-driven, centrifugal fan is a popular choice in residential heating systems. Belt-drive, compared with direct-drive, offers an easy method for adjusting fan speed and air volume. Air volume can also be adjusted by varying the power to the motor or using a volume control damper in the duct in front of the fan. A backward-inclined centrifugal fan is a common choice in larger systems where pressures are higher. The backward-inclined fan costs more initially but runs more efficiently.

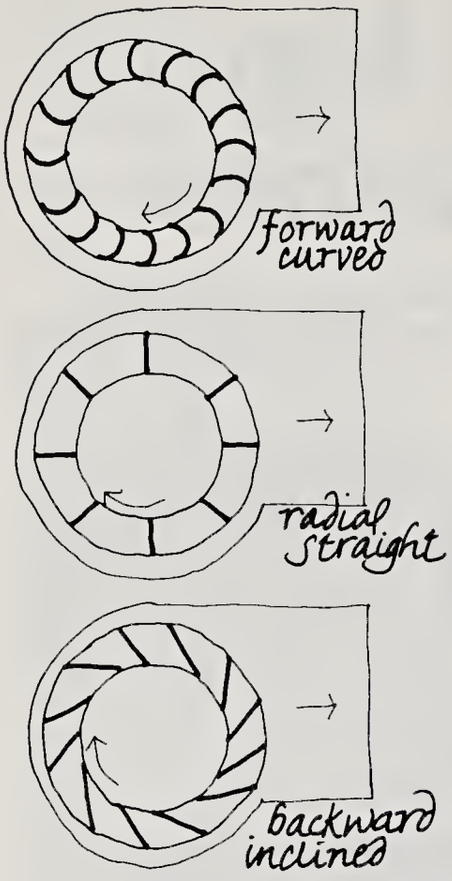
Figure 1.



Fan performance is usually described in terms of the volume of air moved in cubic feet per minute (CFM), the pressure (either static or total) in inches/water gauge (w.g.), the fan input energy in brake horsepower, and the efficiency of the fan. These parameters establish performance curves for specific fans.

Collectors, ducts, dampers, and storage have a certain resistance to the flow of air and, together, contribute to the pressure that the fan will see at a given flowrate. In all but very high pressure systems, the pressure varies as the square of the air volume. According to this relationship, the system itself will have a curve relating the pressure to the air flow.

Choosing the right fan involves, among



other things, matching the fan curve and the system curve to find a suitable operating point, as in Figure 1. There is rarely much room for error. A variation between the actual and the calculated operating point can mean poor fan performance and higher operating costs.

Dampers

Dampers to regulate the air flow in ducts operate in different ways. One damper may perform an on-off function. It opens to allow air flow and closes to stop air flow. Another damper may have positions between open and closed to vary the air flow. (These dampers are generally motor-controlled, although they can be manually operated.) Center-pivoted dampers are common and reliable (Figure 2). Some have parallel vanes, which divert the air flow, while others have opposed vanes, which tend to maintain straight-through flow. Multivane, center-pivoted volume control dampers that can be partially closed mechanically or manually are very helpful in balancing (controlling) the amount of air to different parts of the system.

Air flow tends to put more stress on edge-pivoted dampers and air diverters. Therefore, these dampers need more powerful motors. They do not close as well as the center-pivoted dampers, and are less reliable. Edge-pivoted dampers have caused many problems in solar air systems.

Backdraft dampers, sometimes called back-flow preventers, became very popular with the advent of solar heating systems. These free-floating dampers allow air to flow in only one direction. They swing shut to prevent air from flowing in the reverse direction. Backdraft dampers, however, may be the cause of more problems than any other type of damper. Some plastic films used in these dampers do not stand up to air temperatures or turbulence. Often, the dampers fail to close completely. Metal-vane backdraft dampers may be better, but they can require a fair amount of force to open. Pressure drop increases across them. In addition, metal-vane dampers exposed to cold temperatures on one side and warm air on the other can develop enough condensation to freeze shut during cold weather.

Frisket paper, polyethylene, Tedlar, Teflon, Dacron, nylon, Thermax, and Tyvek are some of the products used in backdraft dampers. Installers report both success and failure using these materials. A definitive solution has yet to emerge from the field. Any damper, especially a backdraft damper, should be accessible or visible through a panel so its operation can be checked.

Controls

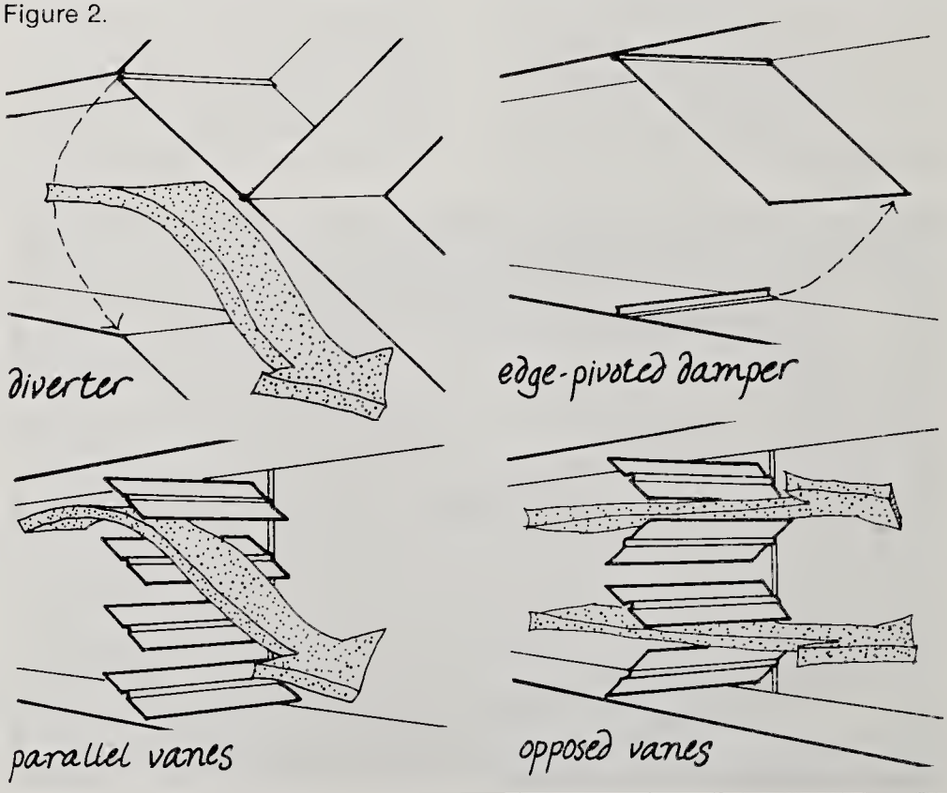
Solar heating systems represent a major departure from traditional HVAC systems because they rely on differential controllers (see *Solar Age*, July 1980, "Controls Demystified"). The controls for solar energy systems are much more complex than the two-wire thermostats of conventional residential heating systems. Most air systems companies manufacture or supply a controller with the system. The controls are generally electronic. Some sophisticated controls use a microprocessor. The outputs are often electromechanical relays for power and reliability. The solar controllers, much improved over the years, are now more dependable and easily serviced. The best controls are flexible: the differentials and set points are adjustable. Other useful traits of controllers are manual-mode operation for testing and troubleshooting, and a readout to indicate the status of the system. Problem areas to watch for are sensor failures and poor instructions, which lead to control installation errors.

Air handlers

Solar heating systems add complexity to residential heating by introducing several modes of operation and the concept of stored thermal energy. Commercial HVAC contractors are familiar with sophisticated mechanical systems and components fabricated on site (called a built-up system). Residential contractors are not. In an effort to simplify the arrangement of blowers, dampers, and controls, manufacturers developed air handlers specifically for residential solar air systems. These "black boxes" take the complexity out of the installation by providing the contractors with an off-the-shelf unit that they can install simply. But many of the first (and some of the later) air-handling units disregarded established practices, creating serious problems for otherwise viable solar energy systems.

Some air handlers with edge-pivoted dampers bind, stick, or drag. Often, they unseat, opening partially during operation because of static pressures on either side of the damper. This causes leaks and

Figure 2.



short-circuits the air flow. Blower and damper motors located in the hot-air stream can overheat. At the very least, this condition can reduce operating life.

Another factor has been often overlooked. The performance of the air-handler unit is not the same as that of the blower operating alone. The air-handler box and dampers add to the pressure drop of the system. More than one company, however, has listed the performance of the blower as if it were the performance of the air-handler unit. When installed, these units actually gave less air flow than expected.

Several manufacturers have developed very respectable air handlers, improved through a combination of engineering and experience. Several use top-of-the-line components, such as dampers and blower motors that have actually been redesigned to cope with the stringent demands of a solar air heating system. General Electric, for example, has developed motors for at least two solar companies that can withstand continuous operation in high-temperature environments with no servicing for 10 years or more. These companies also use high-quality dampers modified to reduce the air leakage even more.

Ducts

With its round or rectangular ducts, turns, transitions, and connections, the air transport system is a critical part of the heating system. Leaky or poorly designed ducts make even the most efficient solar collectors ineffective. Major HVAC manufacturers and professional organizations provide methods for sizing and designing duct systems.

Capsule Checklist—Active Air Systems

System

- ☐ Is it clear what parts and components are supplied by the manufacturer?
- ☐ Is the system guaranteed?
- ☐ Does the system meet state and local building codes?
- ☐ Are local people available to service and maintain the system?

Fans

- ☐ Has the fan been engineered specifically for the system?
- ☐ Is the fan performance adequate for the system? Will it move enough air at the static pressure of the system?
- ☐ Can the fan speed and air volume be adjusted?
- ☐ Is the fan located so that it can be serviced?

Dampers

- ☐ Are the dampers accessible to determine if they are operating properly?
- ☐ Are damper motors and dampers matched for proper operation?
- ☐ Are dampers center-pivoted whenever possible with no chance of sticking or dragging?
- ☐ Are dampers well made and sealed tightly?
- ☐ Are damper motors accessible for servicing?

Auxiliary Heating

- ☐ Do you understand how the solar energy system and the backup heating system work together?
- ☐ Does one thermostat control the entire system, solar and auxiliary?
- ☐ Is it clear that the thermostat should be set and then left alone?

Air Handlers

- ☐ Does the air handler have a proven track record?
- ☐ Are the motors for dampers and blowers accessible for servicing and adjustment?
- ☐ Is the rated performance (CFM vs. static pressure) for the air handling unit rather than for only the blower inside?

Controls

- ☐ Are control instructions complete and understandable?
- ☐ Is a troubleshooting guide included?
- ☐ Can the controller be wired, installed, and serviced by a local professional?
- ☐ Are sensors accessible so that they can be replaced if necessary?
- ☐ Is the controller adjustable for fine-tuning the system's performance?

Ducts

- ☐ Have ducts been carefully designed and laid out?
- ☐ Has the pressure drop for the duct system been calculated?
- ☐ Are the transitions smooth, without drastic turns?
- ☐ Are ducts round or close to square whenever possible?
- ☐ Are duct air velocities below 1,000 ft/min?
- ☐ Are flexible duct runs oversized to compensate for their higher pressure drop?
- ☐ Are the ducts sealed and taped?
- ☐ Are the ducts insulated where they carry warm air?

Installation & Completion

- ☐ Are all materials available and ready for the installation crew?
- ☐ Are the contractors and subcontractors clear about their roles in the installation and hookup—what to do and how to do it?
- ☐ Is someone scheduled to do the final start-up, testing, and balancing?

Rock Storage

- ☐ Has the rock storage been designed and engineered according to accepted practices?
- ☐ Have the rock bin and the entering and exit ducts been sealed against leakage?
- ☐ Is the bin well-insulated?
- ☐ Is the pressure drop less than 0.25″ w.g. across the bin?
- ☐ Is the face velocity of air less than 30 ft/min through the bin?

Any departure from smooth, round, and straight duct runs will introduce pressure losses in the system. When right-angle turns are made, turning vanes should be used (Figure 3). Drastic transitions are bad.

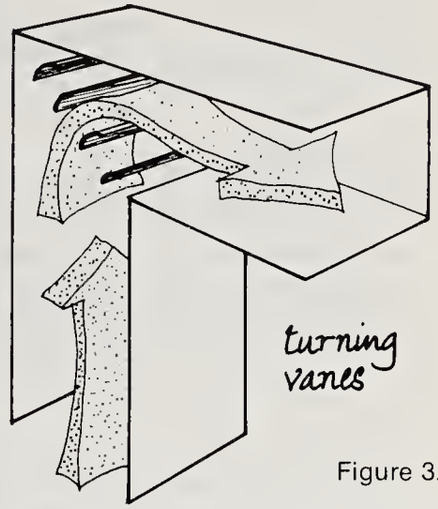


Figure 3.

Air velocity in a duct is found by dividing the air volume in CFM by the cross sectional area of the duct. For example, if the volume were 600 CFM in an 8-inch x 12-inch duct, the velocity would be:

$$600\ \text{ft}^3/\text{min} \div (8\text{-in.} \times 12\text{-in.}) \times 144\ \text{in}^2/\text{ft}^2 = 900\ \text{ft/min}$$

but if the volume were 800 CFM, then the velocity would be:

$$800\ \text{CFM} \div (8\text{-in.} \times 12\text{-in.}) \times 144\ \text{in}^2/\text{ft}^2 = 1200\ \text{ft/min}$$

In residential air systems, duct velocities should be kept below 1000 ft/min. Usually, they are in the range of 600 to 1000 ft/min. Ducting is sized so that it has a pressure drop of less than 0.1″ w.g. per 100 ft. of duct. Air velocities at grilles and registers should be kept below 400 ft/min and even lower if the delivery air temperature is to be less than 100°F. Sizing tables are usually calculated for smooth galvanized metal duct. If other types are used, the pressure drops are usually greater, and the duct sizes should be increased. Fiberglass duct board has a pressure drop 1.35 times greater per unit length than galvanized duct (the "correction factor" is 1.35). Flexible insulated duct, which is becoming more popular for use in solar energy systems, has almost twice the pressure drop of galvanized duct when it is fully extended. If it is compressed by only 10 percent, which is conservative considering how it is often installed, the correction factor goes up to 3.65.

Fiber board ducting and flexible insulated ducting deal with two critical concerns in solar air heating systems. One is air tightness (leakage) in the ducts. The other is insulation in unheated or semi-heated spaces. All seams and connections in the ducts should be sealed with a long-lasting sealant, such as silicone. Then, joints should be taped. Gray cloth-type duct tape is *not* acceptable. It dries out, becomes brittle and cracks, and usually

doesn't adhere after a short time under heat. The metal duct tape (SMACNA approved) is best. It should be pressed on with a nylon applicator or flat straightedge. Rubbing it on with your hand won't insure a proper bond.

Ducts carrying hot air through unheated spaces should be insulated with 2 inches of duct wrap. In partially heated spaces, 1 inch of duct wrap is sufficient.

Auxiliary heat

With few exceptions solar heating systems need back-up heat sources in the coldest winter months. Linking the solar and auxiliary systems can be done in parallel or in series (Figure 4). The parallel combination allows each system to operate alone. In the simplest configuration, the two systems are completely separate with their own controls. This is the method often used in retrofit applications with a gas or oil furnace. When systems share ducts, air must not blow back through one unit while the other is operating. This is usually accomplished with backdraft or motorized dampers.

In a series of configuration, the auxiliary heater is in line with the solar heating system. An electric duct heater, for example, is installed in the main distribution duct. When solar heat is not available, the electric unit heats the air blown past it by the solar air mover. The sequence of solar and auxiliary is often controlled with a two-stage thermostat. Usually, the first-stage calls for solar heat. The second-stage brings on the auxiliary heat. The first-stage operates when the room temperature drops to the thermostat setting. If the room cools off another couple of degrees, the second-stage comes on. Often, when anyone raises the thermostat, both solar and auxiliary systems come on. In this configuration, setting the thermostat up automatically brings on the auxiliary heater whether solar heat is available or not. To make the most of the solar heat, some controllers delay the operation of the auxiliary unit when solar heat is available from the collectors or storage. Others delay the auxiliary for a fixed period of time.

A special problem arises when a heat pump is the backup. A heat pump is basically a two-stage system. The first-stage is the heat pump operation, and, the second-stage brings on an electric resistance backup. Combined with a solar energy system, the heat pump results in a three-stage system. Careful coordination of separate thermostats for each system is one way of handling the controls. New to the market, three-stage thermostats can also do the job. Honeywell makes one.

Rock storage

Rock storage is unique to solar air heating systems. The major solar manufacturers have detailed rock storage designs in their manuals.

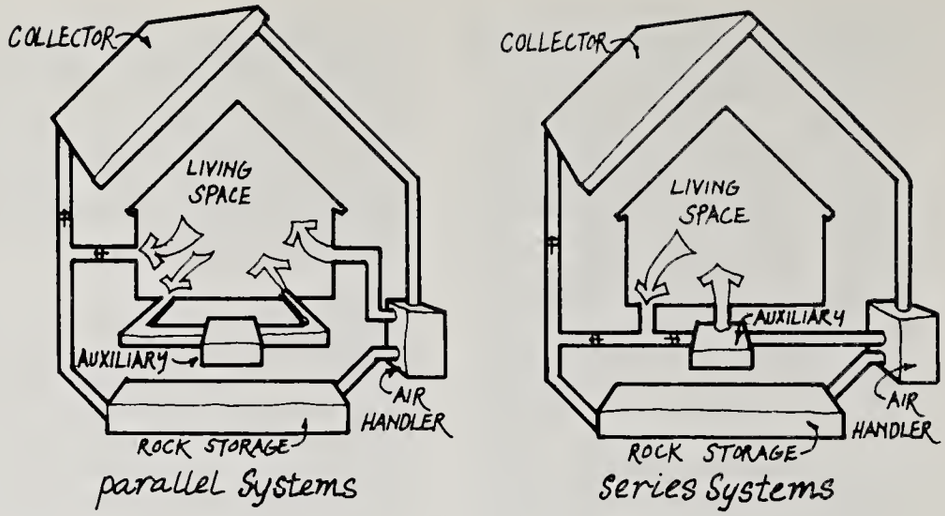


Figure 4.

The key point is that the rock bin is a part of the air transport system. It should be airtight. The entrance and exit ducts must be carefully sealed where they join the bin. The rock bin should be well insulated. A minimum insulation level on all sides is R-24. R-30 is recommended. This can be reduced if heat loss to an adjacent living area is desired.

Air flow is an important element of rock storage. The plenums should be large enough to allow the air to spread out across the entire cross-sectional area of the rocks. The pressure drop in the plenum should be less than the pressure drop in the rocks by a factor of 10 or more. Except in special applications, the pressure drop in the rock bin should be less than 0.25" w.g., and the face velocity of air should be less than 30 feet per minute. (For more information, see "How To Size Rockbeds" in the March 1982 issue of *Solar Age.)*

Installation

Successful companies realize that solar air systems are much more than the collectors. For example, Solaron Corp., which markets internationally, offers the most comprehensive manual and complete documentation of any active air system manufacturer. Contemporary Systems, Inc., limits sales to the Northeast. Its employees are directly involved in the installation process. A CSI field technician accompanies the delivery of each system, spending at least one day on site supervising the installation. In any case, the installer must take time to thoroughly understand the system, whether by reading a manual or by spending time with the manufacturer, or both.

Most companies try to standardize and simplify wherever possible. Even so, the average contractor has had tremendous difficulty getting the installation right the first time through. Ducts weren't sealed or connected properly, sensors and sensor wires were forgotten, or backdraft dampers were left out or put in backwards. The list of errors is long.

Contractors can avoid these errors and end up with a well-installed system by adhering to basic principles. Balancing and testing of air flows and mechanical system components is their final guarantee that the system is working as planned. This is, regrettably, seldom done by residential HVAC contractors. The system should be run through all of its modes of operation several times to make sure the controls, dampers, and motors are operating properly. An amperage and voltage check of the motor insures that the blower is operating correctly. Air flow measurements and static pressure readings around the system (at the inlet and outlet of the collectors, blowers, and rock storage, as well as in the distribution lines) signal that air flow is adequate and pressure drops are as calculated. These measurements are crucial in determining any flaws or problems in the system before it is turned over to the homeowner.

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For More Information

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle N.E., Atlanta, Ga. 30329. *Handbooks: Fundamentals; Equipment; Systems; and Applications.*

Sheet Metal and Air Conditioning Contractors National Association, Inc., 8224 Old Courthouse Road, Tysons Corner, Vienna, Va. 22180. *HVAC Duct System Design Manual.*

Solaron Corporation, 1885 W. Dartmouth Ave., Englewood, Colo. 80110. *Systems Engineering Manual.*

Domestic Hot Water Installations:

The Great, the Good, and the Unacceptable

Skilled inspectors have checked every detail of 170 solar domestic hot water installations in the Northeast. Their conclusions? Most systems are working just fine, but some problems crop up alarmingly often. Here's a guide to preventive troubleshooting for sellers and buyers.

By Jack Meeker and Lew Boyd

The most thorough analysis of installed solar domestic hot water systems ever attempted began in November 1980. The Northeast Solar Energy Center (NESEC), one of the four regional solar authorities working under a contract with the U.S. Department of Energy, enlisted the National Association of Solar Contractors, Inc. (NASC) to help with the project. The purpose of the program was to investigate the state of the art of installation techniques and system durability in the field.

All together, 170 residential solar water heating systems were evaluated in the six New England states, New York, New Jersey, and Pennsylvania. The systems chosen were installed by professionals, had been in service for between one and two years, and proportionally represented the sales activity of various manufacturers in each state.

Six teams of inspectors made the evaluations. Each team consisted of a technician representing the Northeast Solar Energy Center and a NASC contractor. Technicians had a minimum of three years of solar experience. Each contractor had installed over 100 solar domestic hot water systems prior to joining the Site Evaluation Program. The teams received evaluation training at NESEC and were equipped with a full array of diagnostic instruments. They first conducted pilot field inspections to test a specially prepared, 12-page checklist and to ensure that each team conducted its surveys uniformly. The final surveys took place between November 1980 and February 1981, with the crews spending an average of two and one-half hours at each site.

The findings and recommendations of the Site Evaluation Program (SEP) are summarized here for the first time. Many thousands of items checked at the 170 installations were tabulated by computer. Data from the field inspections will be contained in the complete report. The report will include an executive summary outlining major findings, sections on methodology, marketing and economics, and a listing of manufacturers participating by state.

Of the 170 systems inspected, 50 percent were rated as excellent or good in overall workmanship. Over 88 percent were satisfactory in terms of system operation. Some 31 systems were judged to be "Red Stars"—i.e., outstanding. The table below describes the types of systems evaluated:

Closed loop (antifreeze)	156
Drainback	11
Draindown	2
Phase change	1

The overall findings do substantiate that solar domestic hot water heating is technically proven and can effect significant savings even in the climatically rigorous Northeast, if systems are properly installed.

Nevertheless, the study uncovered many recurrent problems in the field. Solar professionals and prospective consumers of solar domestic hot water systems can learn much by studying the report and recommendations of the site evaluation team. The report should prove especially worthwhile for contractors entering the solar field.

Categories marked with an asterisk (*) below indicate areas where errors can severely impair overall performance of the system or create potential hazards. Unmarked categories deserve close attention, too, but these problems were not considered to be as serious.

The installation problems identified in this study led the site evaluation team to recommend that installer certification be considered for the solar industry.

Jack Meeker is an energy systems and HVAC consultant based in Wilmington, MA, and formerly Active Solar Program Manager at the Northeast Solar Energy Center. Lew F. Boyd is vice-president for marketing for Terra-Light, Inc., and former president of Boyd Associates, Bedford, MA.

Orientation and Tilt Angles of Collectors *

Although the overall focus of the program was not system performance, inspectors did reach an informal consensus on orientation and tilt angles: azimuths far off true south (over 45°) and tilt angles under 30° or over 55° appear to impair solar contributions. Systems with azimuths of 60°, for example, do not receive adequate direct radiation, especially during the winter. Systems with tilt angles less than 30° so favor summer performance in the Northeast that snow will not shed in winter.

The watch points true south at solar noon. The performance of DHW systems with collectors oriented at less than optimal azimuths like this one ought to be measured authoritatively.

Recommendations: The industry has been willing to install solar energy systems within wide tilt and azimuth parameters. This issue deserves careful and authoritative study. Performance compromises should be analyzed on a month-by-month basis, given deviations in azimuth from true south, in tilt from an angle equal to the local latitude, and in storage-to-collector ratios. Actual Btu output of comparable equipment and equal demand should be monitored. The validity of computer simulations now in wide use should be verified against these very basic site parameters.

Shading

Shading, mostly by trees, during collector hours was reported in 35 percent of the cases studied, but it was not considered severe in most instances. Still, contractors and homeowners do not have a clear enough understanding of the penalties of shading or of how to predict its occurrence. In a few cases where the collectors themselves caused shading, a sawtooth configuration had been used without sufficient space between the panels.

Sawtooth configurations can lead to shaded collectors when the panels are not spaced properly. The collector in the rear is partly shaded during the early hours of each collection period.

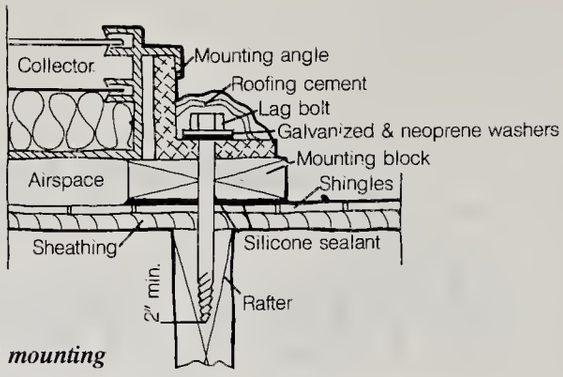
Recommendations: The *HUD Installation Guidelines for Solar DHW Systems* should be followed in all but exceptional cases; i.e., no more than five percent of the collectors should be obstructed between 9:00 A.M. and 3:00 P.M. on an annual basis. Manufacturers should provide siting tools and instructions for their installers.

Collector Mounting *

In roof-mounted collector systems, 32 percent had one or more of the following problems: "flier" (insufficiently attached); wood deterioration; evidence of leaks; dissimilar metals in contact; insufficient spanners/blocking; lag bolts into sheathing only; materials with inadequate strength; spanner not affixed to rafters; or other difficulties.

Many racks seen in the project appeared to be one of a kind. Some were under-designed, others over-designed. As of the end of 1979, few manufacturers offered pre-engineered rack designs and materials.

The most pressing concern of the inspection teams was the actual attachment of the collectors to the roof. Lagging into sheathing only is absolutely unacceptable. If blocking beneath sheathing is not attached to neighboring rafters, the blocks' resistance to uplift forces is reduced drastically. If spanners are not attached to adjacent rafters they can move into the rafter bay.



Lag-bolt mounting

Recommendations: Manufacturers should accept the responsibility of providing fully engineered mounting and rack details suited to the collectors they produce. Similarly, installers must recognize that there are only three techniques considered acceptable for collector and/or rack mounting: spanner, direct lagging into rafters, and blocking. Spanner and lagging techniques are fully described in the HUD solar guidelines. If site considerations preclude the use of these techniques, which are preferable, then blocking is an alternative. A block is cut to fit exactly into each rafter bay where an attachment will be made. The block of a 2 x 6-inch lumber is soundly toed into the rafters with nails. The lag screws or thread rod are then brought through the sheathing, and finally through the blocking as secondary support.

Roof Support *

Homeowners and solar installers sometimes have a hard time judging whether or not a roof is strong enough to support collectors. The inspection teams were given tables of wind and snow loading parameters as they relate to rafter size and spacing, which are part of the Massachusetts State Building Code. The sites were measured against these tables. In 19 cases the roof support was judged to be inadequate. It is interesting to note that only in Massachusetts were certain sites found to have reinforced roof structures under the solar energy system.

The roof here is shored up with additional rafters to support the collector load. The installation also shows an excellent spanner mount. Unistrut stretches from rafter to rafter and is soundly toed in. The threaded rods are attached with two nuts.

Recommendations: All states should follow the example set by the Commonwealth of Massachusetts, which furnishes tables reflecting its particular roof loading parameters.

Use of Wood *

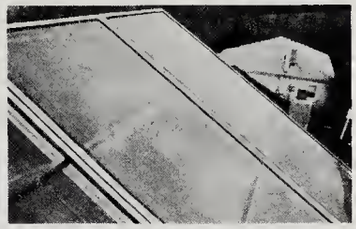
Wood takes extreme punishment when it is exposed to the sun, water, and other weather conditions. Wood has shown signs of thermal degradation when used in collector frames or housings. Untreated wood should not be used in collector mounting, whether in sleepers and stand-offs or full-scale collector stands.

Untreated wood should never be used in rack-mounted roof systems like this. The rack is also straddling the roof ridge, secured only by the feed and return piping to the collectors.

Recommendations: Racks fabricated from similar metals are preferred to wood for reasons of longevity. If wood must be used, all wood components should be pressure-treated and fully accessible for service.

Condensation and Outgassing

Condensation in collectors can reduce the thermal quality of the insulation over time. This condition also causes much concern among homeowners. Outgassing can severely reduce the transmissivity of cover glazing. Of the reporting cases, about 20 percent had evidence of condensation in one or more collectors. One in eight of the systems studied showed collector outgassing.

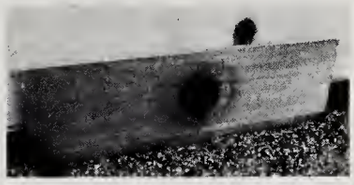


Outgassing and condensation are related to certain brands of collectors. The manufacturers should correct such defects.

Recommendations: Condensation and outgassing tended to occur in certain brands of collectors. A correlation appears to exist between condensation and the use of urethane collector insulation. This problem points to manufacturers rather than installers. Makers should give these problems more attention, and installers should carefully check the record of the manufacturers.

Corrosion

Most corrosion noted in the SEP involved screws, nuts, bolts, and other fasteners used to hold panels together. Plating of the hardware was often deteriorating. There was no meaningful correlation with time—manufacturers had not made significant progress in this area by late 1979 when compared with early 1978.



Corrosion shown here on the collector housing is a manufacturer's flaw. Corrosion appearing on the mounting standoff is the contractor's fault. When corrosion on the standoff worsens, the collector can become a "flier."

Recommendations: Collector manufacturers should give considerable attention to the fasteners they use outdoors. Compatible, weather-resistant materials must be used. Particular attention should also be given by the installer to the use of compatible materials in the mounting of collectors.

Sensors

The teams paid close attention to sensor placement, attachment, wire splicing, etc. Most collector sensors that could be seen were installed properly. Those that appeared safest, however, were attached to the absorber plate by manufacturers using a screw or a rivet. These sensors were completely protected from ambient air conditions and moisture.

In a few cases solar tank sensors were mounted improperly. Adequate tank/sensor thermal contact is necessary. Sensors should not be affixed to the cold water inlet instead of the tank, nor to the solar loop itself.

In this installation sensor wire to the thermistor is exposed to ambient moisture, which will find its way into the splice and fool the controller. The safest sensors are those attached to the absorber plate by the manufacturer.

Recommendations: Because the controller subsystem is critical to system operation, correct placement and installation of sensors is the key. More manufacturers should consider factory installation of collector sensors. Whenever sensors are factory mounted, built-in trap doors should be supplied to provide easy access for servicing. This technique will also allow spliced wire connections to be protected from ambient weather conditions.

It is also recommended that manufacturers or packagers provide specific installation instructions as to where and how to mount tank sensors. Tank manufacturers should provide mounting clips in the appropriate spot. These clips should be easily accessible for installation and service in the field.

Piping and Penetration

Poor piping configurations and inadequate materials can impair system performance. Improper techniques used in penetrating the building envelope with piping can result in damage to the structure. A variety of problems appeared in this area.

Some 29 systems were piped as "C-flow," where both supply and return piping is at one end of the collector array. In systems with more than two collectors, this arrangement frequently results in thermal imbalance across the array.

In almost one fifth of the systems visited, the collectors were undrainable. A similar number of systems were reported to have loop piping that did not meet accepted pipe hanging standards.

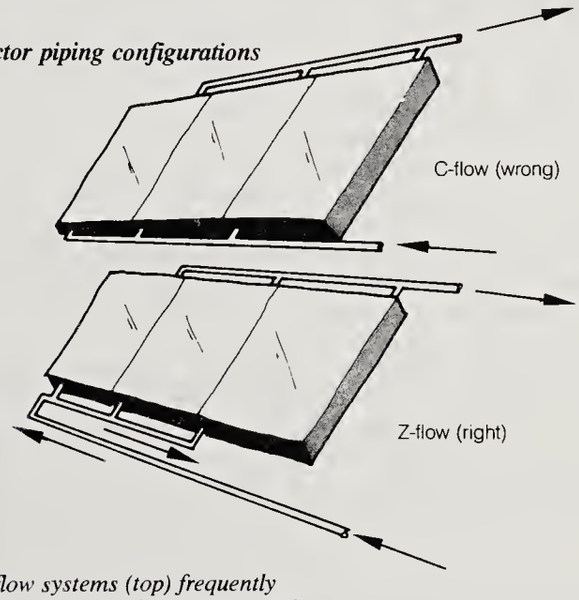
Eight systems studied used CPVC for the solar loop. Of these, seven were observed to have unacceptable distortion and waving in the loop.

Finally, and perhaps most importantly, 20 percent of the sites studied included solar loop penetrations into the building envelope that were judged unsatisfactory because they permitted water to leak to the inside.

The snug-fitting, shoe-type penetration is recommended for clean and water-tight piping on roof-mounted domestic hot water systems.

Recommendations: For standardization and simplicity, all solar energy systems, regardless of the number of collectors, should be installed using "Z-flow," (reverse-return) configuration. Whenever possible, collectors should be piped so that they can self-drain. When this is impossible, a manual drain should be installed at the collector low point.

Collector piping configurations



C-flow systems (top) frequently create thermal imbalance across the array. The Z-flow (bottom) configuration, or reverse-return, is better for all solar energy systems.

The SEP team recommends close adherence to the *HUD Installation Guidelines for Solar DHW Systems*, which provides

strict standards for hanging techniques and intervals for copper tubing and threaded pipe. In this study, rigid plastic pipe (CPVC) did not appear appropriate for solar DHW applications. The distorted piping observed was apparently losing rigidity under high loop fluid temperatures. If, after further investigation, CPVC is found to be able to withstand typical solar loop temperatures over time, new standards for hanging techniques and intervals need to be established.

Watertight penetrations for piping are critical to the quality and durability of an installation. The SEP team recommends the use of the no-caulk roof shoe used often and successfully by the building industry. If proper 1-inch-wall insulation is used over the piping, a 2-inch roof shoe fits snugly over the insulation, giving an easy, clean penetration. Small holes in the roof can be treated with silicone sealant, which can be placed around the roof shoes for extra protection.

Pipe Insulation

One of the most recurrent problems encountered was the insufficient quality of loop insulation. The problems fall into three areas: R-value, sealing, and ultraviolet degradation. The site evaluation team found that the industry falls far short of the *HUD Installation Guidelines*, which call for minimum insulation of R-4 on all solar loop piping, R-6 on pipe of 1-inch diameter or greater. Elastomer is used widely but the thickest wall size reported was ¾-inch, which affords an R-value of less than half the HUD recommendations. Insulation must be properly closed and sealed. The elastomer insulation in many systems had been slit and placed over the piping after the piping had been installed. Shrinkage of the insulation then often exposed large gaps. Sealing is critical on outside loop piping, where temperature differentials are great. Small slits and cracks worsen over time with intermittent exposure to sun, rain, snow, and ice. Sealing all seams with silicone or mastic seems to outlast all other techniques.

Elastomer insulation has undergone dramatic ultraviolet degradation in this system. Materials should be selected for solar transport systems based on their ability to withstand exposure to weather and ultraviolet radiation.

The investigation of 102 systems using elastomer insulation outside pointed conclusively to the fact that this material is not suitable for the application. In virtually every case, some ultraviolet degradation was noted. Some contractors seal outside insulation with ordinary paints. These coatings generally do not hold up well; deterioration was dramatic. Metal claddings, ultraviolet-inhibited PVC jackets, and "do-all" jackets, on the other hand, all appear to be lasting well.

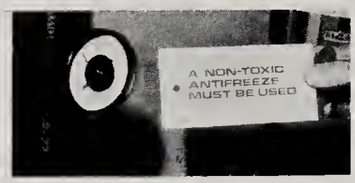
Recommendations: The team strongly recommends that the industry as a whole concentrate on insulation of solar transport systems. In terms of R-value, the *HUD Installation Guidelines* minimum of R-4 must be followed. One-inch thicknesses of urethane, fiberglass, and phenolic foam are among the few pipe insulations readily available that conform to this requirement. Other materials, such as elastomer, must be avoided. Much more attention should be given to sealing insulations to maintain thermal quality and weather protection outside. Manufacturers and installers should also understand the effect of ultraviolet light on outside insulation and select materials on this basis.

Heat Transfer Fluids *

Propylene and ethylene glycol antifreeze solutions occasionally become acidic, although ethylene glycol solutions appear to be the more stable of the two. No correlation was found with factors like length of operation or system size to explain why particular systems turned acidic. But in 39 percent of the systems using a controller that features a high limit shut-off, propylene glycol was reported at pH 6.5 or less. Allowing fluid to boil in stagnating collectors appears to contribute to pH degradation.

In all four systems that used glycerin, the pH balance was acidic. There was no evidence of abnormal stagnation exposure in these systems or any special factors that might have contributed to the problem.

Six of the seven silicone-oil-charged systems showed signs of some leakage, especially at threaded connections and around the air purger assembly. Yet, the seepage was not severe. The lowest loop pressure reported for these seven systems was 15 psi, which was satisfactory given the short distance from the tank to the top of the collectors.



Over 50 percent of the domestic hot water systems inspected in the project had no labels to indicate what heat transfer fluid was used. Labels are vital for service and safety.

The freeze strength of ethylene and propylene glycol-charged loops was measured in 128 systems. Freeze strengths of less than −21°F were considered too weak in the rigorous climate of the Northeast. Some 34 percent of the systems were inadequate. Most of the antifreeze solutions were presumably supplied pre-mixed by manufacturers to achieve a freeze level of at least −40°F. The team inspectors theorize that installers, instructed by the manufacturer to flush the loop with water after piping it, are not purging all of the water from the loop before charging it with antifreeze. Simply opening boiler drains at the solar tank would be insufficient in many cases where undrainable low spots in the loop were noted. In four systems the weakness of antifreeze was easily explained. The contractor had left a washing-machine-type hose connected between the incoming cold water supply and the fill/drain assembly on the solar loop. Homeowners were told to open the valves and let some street water into the loop whenever the solar loop pressure dropped below 10 pounds.

Despite warning signals, it is noteworthy that none of the antifreeze systems visited had frozen up.

Finally, over half of the systems inspected had no labeling to indicate what heat transfer fluid was used.

Recommendations: The problem of glycols becoming acidic deserves further study. However, controllers with upper limit shut-offs should not be used with glycol systems. The team recommends that pH balance of all glycol systems be checked, along with the freeze strength, once a year. Whenever the solution drops below a pH of 6.5, it should be changed. Manufacturers who wish to use glycerin should perform careful time, temperature, and pH studies. Otherwise, they should instruct installers to be prepared to change the fluid often. Manufacturers and packagers who supply silicone oils with their systems should pay more attention to helping contractors install leak-proof loops.

Installers should be careful to drain the flushing water from loops. All low spots in closed-loop systems must have drains. Upon filling and purging a system with a glycol solution, freeze strength must be checked with proper equipment and noted on the fill label attached to the system. Unlabeled systems are unacceptable from a safety and service point of view. The team recommends full and immediate adherence to the *HUD Intermediate Property Standards*. Contractors should fill in tags provided by manufacturers with their equipment describing installation date, fluid type, quantity, pH, and freeze point.

Valves and Vents *

The team studied 156 closed-loop systems. Of 128 systems reporting, 30 percent did not have pressure relief valves on the solar loop to allow antifreeze to escape if maximum allowable pressure were exceeded. Of these systems, 53 percent were produced by one system manufacturer. The team was surprised to find *any* systems

without pressure relief valves. This lack represents a safety hazard in clear violation of all national plumbing codes. Slightly over 10 percent of 163 cases reporting had no temperature/pressure relief valve on the storage tank. Failure to install such relief valves constitutes the most severe safety hazard in the solar plumbing trade. Almost one half of the systems investigated did not have tempering valves, permitting the possibility of severe scalding. Finally, over one fifth of the closed loop systems did not have proper air vents at the collector high point.

This air vent at the collector high point is incorrectly positioned. Air vents should be perpendicular to the ground, not perpendicular to the collector.

Recommendations: The team recommends that manufacturers and packagers provide pressure relief valves and that installers always include them with closed-loop systems. In recent installations, relief valves, when installed, were usually placed inside the home, often as part of the air purger assembly, where they can be vented to a safe location. This is good practice because antifreeze sometimes stains and damages roofing materials.

Temperature/pressure relief valves must be installed on all pressurized vessels. The manufacturer or packager has the responsibility to include these valves with systems.

Storage Tanks

The site evaluation team was surprised to find that 51 percent of the storage tanks examined were placed in what was considered an unheated area. In concert with inadequate insulation, this underscores a lack of understanding of standby losses by the solar industry. In certain isolated cases, rather remarkable placements were observed. A tank, for example, was buried in an uninsulated hole in a crawl space, making servicing all but impossible.

Of 159 reported cases, 70 percent had no on-site insulation added to the solar storage tank. HUD standards mandate a minimum of R-11 on storage tanks. The team inspectors felt that none of the tanks without additional insulation complied with this standard. Packagers and manufacturers do not encourage installers to add insulation when they paint the tanks special colors and place decals on them with information about the system.

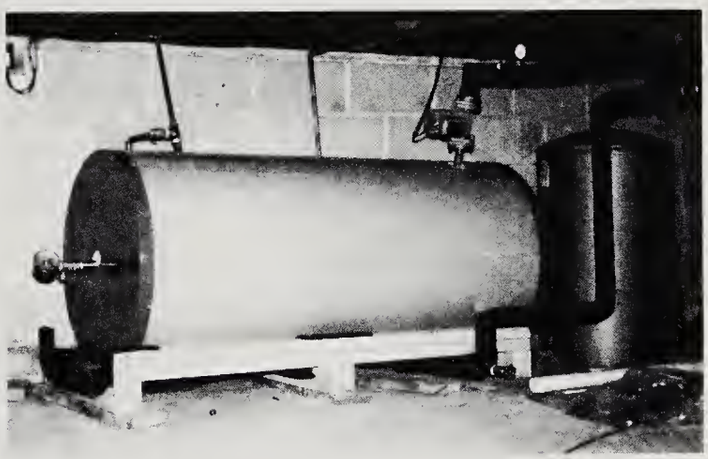
Although some tanks were insulated on-site, most—though not all—of the work was sloppy. Some wraps looked leaky and unprofessional.

The solar tank in this domestic hot water system is properly insulated, and the wrapping is neat. The installer, however, failed to insulate the auxiliary tank.

Nearly four out of five systems used the solar tank as a preheater to a second tank or to a tankless coil. A number would have benefited from a bypass interface. Most homeowners indicated that they try to keep the backup turned off during the summer. The most efficient way to do this with a double-tank system or a tankless coil is to bypass the second energy source altogether during times of favorable solar collection.

Recommendations: Manufacturers must be much more specific in their installation manuals about straightforward considerations such as tank placement. If tanks must be placed in unheated areas, insulation of R-20 minimum is strongly recommended. Tanks must be installed so that they can be serviced. Solar tank losses are known to be severe, often 4 million Btu a year, plus or minus, in an unheated location. Specially cut tank wraps and kits should be a common component of the solar hot water package.

The pitch of this roof is 23°. Snow fell five days before this picture was taken and still had not shed from the shallow-mounted collectors.



Horizontal placement of this stonelined storage tank is a mistake. The stone lining could fall, and the electrical heating element will not produce proper temperature stratification within the tank. Standby losses will be substantial because the tank is placed in an unheated area and has too little insulation.

Finally, the team recommends that installers become familiar with bypass techniques and use them more often. Homeowners seem ready and willing to deal with the valves and switches. The savings can be substantial.

Monitoring and Manuals

Systems that have no thermometers on the domestic water outlet of the storage tank afford the homeowner no opportunity to know whether the system is producing a meaningful amount of heat. More thermometers were installed by contractors on the loop than on the hot water outlet at the tank.

In nearly one-third of the cases studied, a system manual was not left with the homeowner. Several homeowners admitted to a total lack of knowledge about their systems.

Recommendations: For homeowner monitoring and for system diagnosis and service by the installer, three thermometers should be standard in all solar water heaters: one on the domestic water outlet as an overall measure of system operation, and two on the solar loop—one on the supply and the other on the return. Manufacturers should include the three thermometers as standard components. The team strongly urges manufacturers and packagers to supply manuals explaining the operation of their equipment. Installers should provide manuals to the consumer describing the proper use of the system. ☼

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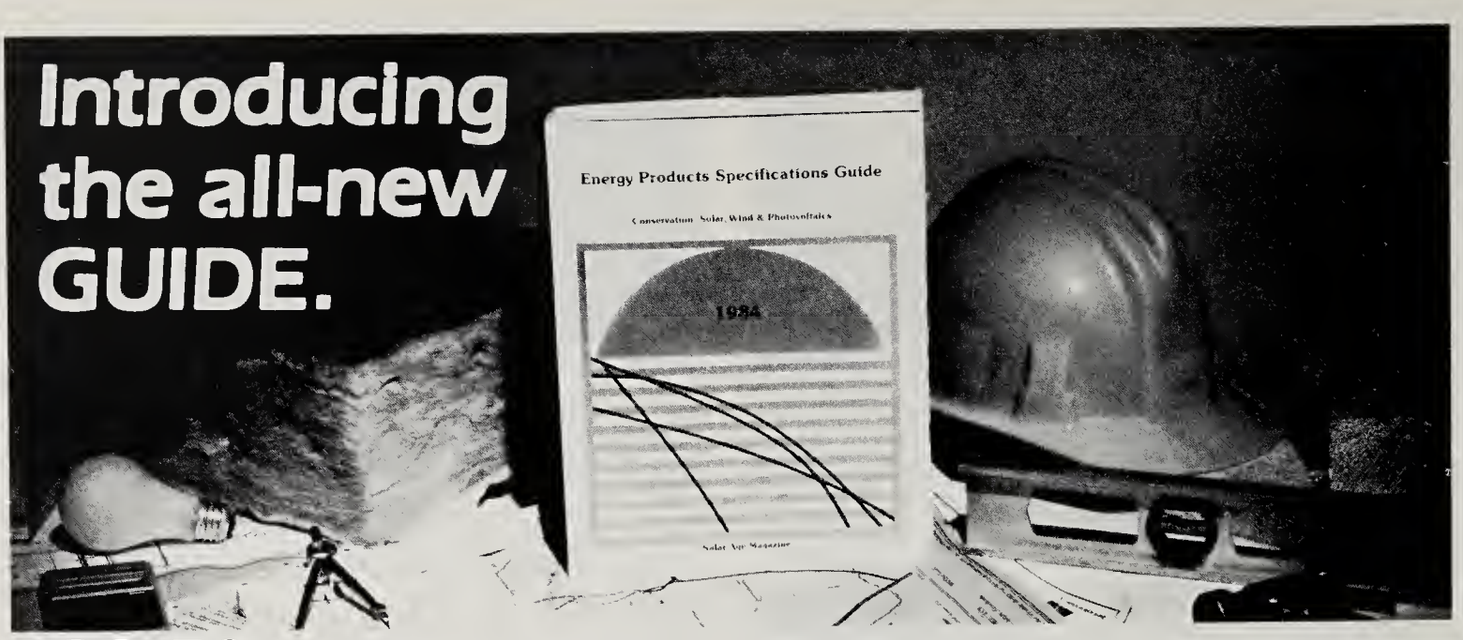

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A GLOSSARY OF SOLAR HOT WATER TERMS

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SDHW GLOSSARY

Absorber - the surface in a collector that absorbs solar radiation and converts it to heat energy; generally, matte black surfaces are good absorbers and emitters of thermal radiation, while white and metallic surfaces are not (see Selective Surface).

Absorptance - the ratio of energy absorbed by a surface to the energy striking it.

Active System - a solar heating or cooling system that requires external mechanical power to move the collected heat.

Air-type Collector - a collector that uses air as the heat transfer fluid.

NOTE: The majority of this glossary is reprinted from "Installation Guidelines for Solar DHW Systems on One- and Two-Family Dwellings" by the U.S. Department of Housing and Urban Development.

Altitude - the angular distance from the horizon to the sun.

Ambient Temperature - the temperature of surrounding outside air.

Angle of Incidence - the angle at which solar radiation strikes a surface.

Anode - an electrically positive metal, such as a magnesium rod placed in steel water storage tanks to prevent tank corrosion.

Aperture - the opening through which solar radiation enters a solar collector, also called Net Area (see Gross Area).

ARI - Air-Conditioning Refrigeration Institute.

ASHRAE - abbreviation for the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Autoignition Temperature - temperature at which a material begins to burn in the presence of oxygen.

Auxiliary Heat - the extra heat provided by a conventional heating system for period of cloudiness or intense cold when a solar heating system cannot provide all needed heat.

Azimuth - the angular distance between true south and the point on the horizon directly below the sun.

Batch Heater - a non-circulated passive solar water heater in which solar radiation is absorbed in a tank of water, also called integral passive heater (IPH).

British Thermal Unit (Btu) - the quantity of heat needed to raise the temperature of one pound of water one degree Fahrenheit.

Calorie - the quantity of heat needed to raise the temperature of one gram of water one degree Celsius.

Centrifugal Pump - a pump type in which rotating blades (the impeller) whirl the fluid outward to the discharge of the housing (the volute).

Closed Loop - any loop in the system which is not exposed to the atmosphere.

Coefficient of Heat Transmission - the rate of heat loss in Btus per hour through a square foot of wall or other building surface when the difference between indoor and outdoor air temperatures is one degree Fahrenheit (also called U-value).

Coefficient of Performance (COP) - a ratio of the useful energy delivered by a device or system to the input energy necessary to operate the device or system (see Parasitic Energy).

Collector - a device that collects solar radiation and converts it into heat.

Collector Efficiency - the ratio of usable heat energy extracted from a collector to the solar energy striking the cover.

Collector Tilt - the angle between the horizontal plane and the solar collector plane.

Concentrating Collector - a device that concentrates the sun's rays on an absorber surface which is significantly smaller than the overall collector area.

Conductance - the rate of heat flow (in Btus per hour) through an object when a $1^{o}F$ temperature difference is maintained between the sides of the object.

Conduction - the flow of heat due to temperature variations within a material.

Conductivity (k-value) - a measure of the ability of a mterial to permit conduction heat flow through it.

Convection - the motion of fluid such as gas or liquid by which heat may be transported (see Gravity Convection).

Counter-Flow - a flow pattern in a heat exchanger in which the two heat transfer fluids flow in opposite directions past the transfer surface.

Cover Plate - a sheet of glass or transparent plastic placed above the absorber in a flat-plate collector (see Absorber, Collector and Glazing).

Degree-day - a unit that represents a $1^{o}F$ deviation from some fixed reference point (usually $65^{o}F$) in the mean daily outdoor temperature.

Demand Load - domestic water heating needs to be supplied by solar or conventional energy.

DHW - Domestic Hot Water.

Dielectric Union - a union used to join dissimilar metals (such as copper and steel) which electrically isolates the metals and thus prevents galvanic corrosion.

Diffuse Radiation - indirect sunlight that is scattered from air molecules, dust, and water vapor.

Direct Radiation - solar radiation that comes straight from the sun, casting shadows on a clear day.

Domestic Water Pressure - the pressure of the potable water within the building from sources not related to the solar domestic hot water system.

Double-glazed - covered by two panes of glass or other transparent material.

Double Wall Separation - heat exchangers using nonpotable heat transfer fluids are separated from the potable water system by use of two walls between the fluids.

Drain Back System - a system in which freeze protection is achieved by draining solar collectors and piping to a tank.

Drain Down System - a system in which freeze protection is achieved by draining solar collectors and piping to a sewer drain.

Dual-Tank System - a system that uses two tanks connected in series; the first tank is for solar preheating and the second tank is for auxiliary or back-up water heating (see Single-Tank System).

Emittance - a measure of the propensity of a material to radiate energy to its surroundings.

Erosion - the wearing away of material caused by high fluid velocity past a surface.

Evacuated Tube Collector - a collector type that uses specially coated concentric glass tubes with a vacuum space between the tubes to reduce heat losses.

External Heat Exchanger - an exchanger which is outside the storage tank through which the two heat transfer fluids are pumped.

F-Chart - a design method for solar heating systems used to estimate the long-term energy delivery by the system.

Fire Point - the temperature at which sustained burning of a material will occur if supplied with oxygen.

Flat-plate Collector - a solar collection device in which sunlight is converted into heat on a plane surface without the aid of reflecting surfaces to concentrate the rays (see Collector0.

Flash Point - the temperature at which a material will give off vapors sufficient to form a flammable mixture with air.

Forced Convection - the transfer of heat by the flow of fluids (such as air or water) driven by fans, blowers, or pumps.

Galvanic Corrosion - the condition caused as a result of a conducting liquid making contact with two different metals that are not properly isolated physically and/or electrically.

Getters - (sacrificial anodes) - a solumn or cartridge containing an active metal which will be sacrificed to protect some other metal in the system against galvanic corrosion.

Glazing - transparent material used to cover solar collectors.

Gravity Convection - the natural movement of heat that occurs when a warm fluid rises and a cool fluid sinks under the influence of gravity (see Convection).

Gross Area - the overall area of a solar collector (see Aperture).

Head - a vertical distance commonly measured in feet of water.

Header - the pipe that runs across the edge of an array of solar collectors, gathering (or distributing) the heat transfer fluid from (or to) the risers in the individual collectors. This insures that equal flow rates and pressure are maintained (see Risers).

Heat Capacity - a property of a material denoting its ability to absorb heat.

Heat Exchanger - a device, such as a coiled copper tube immersed in a tank of water, that is used to transfer heat from one fluid to another through a separate wall.

Heat Removal Factor (F_R) - the ratio of the actual useful energy gain of a solar collector to the gain if the whole collector were at the fluid inlet temperature.

Heat Storage - a device or madium that absorbs collected solar heat and stores it for use during periods of inclement or cold weather.

Heat Storage Capacity - the amount of heat that can be stored by a material.

Heating Season - the period from early fall to late spring (in the Northern Hemisphere) during which additional heat is needed to keep a house comfortable for its ocupants.

Hybrid Solar Energy System - a system that uses both active and passive methods in its operation (see Active System and Passive System).

Hydronic System - a system that uses a liquid or combination of liquids as transfer fluids.

Incident Angle Modifier - a correction factor for solar collector performance used to account for incident angles other than perpendicular (normal).

Infrared Radiation - electromagnetic radiation from the sun that has wavelengths slightly longer than visible light.

Inhibitors - compounds added to heat transfer fluids to inhibit corrosion and chemical changes.

Insolation - the total amount of solar radiation - direct, diffused, and reflected - striking a surface exposed to the sky.

Insulation - a material with high resistance (R-value) to heat flow.

Isogonic Chart - a chart that shows magnetic compass deviations from true north.

Internal Heat Exchanger - an exchanger which is immersed in the storage tank through which a heat transfer fluid is pumped.

k-value - (see Conductivity) Btu/hr/ft^2/^{o}F per inch.

Kilowatt - a measure of power equal to one thousand watts, approximately 1 1/3 horsepower, ussually applied to electricity.

Kilowatt-hour (kWh) - the amount of energy equivalent to 1 kilowatt of power being sued for one hour; 3,413 Btu.

Langley - a measure of solar radiation; equal to one calorie per square centimeter.

Liquid-type Collector - a collector using a liquid as the heat transfer fluid (see Collector).

Log Mean Temperature Difference - a logarithmic average of the inlet and exit temperatures of a heat exchanger used to calculate the performance of the exchanger.

Natural Convection - see Gravity Convection.

Net Positive Suction Head (NPSH) - the pressure required on the suction (inlet) side of a centrifugal pump at the center of the impeller to prevent the fluid in the pump from vaproizing at any given temperature.

Open System - a system in which some part is vented to the atmosphere, or the system contains fresh or changeable water.

Passive System - an assembly of natural and architectural components that converts solar energy into usable or storable termal energy (heat) without mechanical power.

Parasitic Energy - operational energy input for pumps, fans, controls, etc., necessary to operate a solar system.

Payback - the period of time necessary for accumulated energy savings to balance the initial cost of an energy savign system.

Percent Possible Sunshine - the percentage of daytime hours during which there is enough direct solar radiation to cast a snadow (see Direct Radiation).

Photovoltaics - the direct conversion of solar radiation into electricity.

Pour Point - the temperature at which a liquid "sets up" or gels so that it cannot flow.

Pump Curve - a graph of the head versus flow rate for a particular centrifugal pump.

Pyranometer - an instrument for measuring solar radiation (see Solar Radiation).

Radiation - the flow of energy across open space via electromagnetic waves such as visible light.

Reflected Radiation - sunlight that is reflected from surrounding trees, terrain, or buildings.

Refrigerant - a liquid such as Freon that is used in cooling devices to absorb heat from surrounding air or liquids.

Relief Valve - a safety valve used to prevent the build-up of temperature and/or pressure in a closed system.

Reradiation - radiation resulting from the emission of previously absorbed radiation.

Resistance (R-value) - the tendency of a material to retard the flow of heat.

Retrofitting - the addition of a solar heating or cooling system to an existing building.

Return on Investment - a ratio of the annual energy savings to the initial cost of an energy saving system, expressed in percent.

Risers - the flow channels or pipes that distribute the heat transfer fluid from the headers across the face of an absorber plate (see Header).

Roof Jack - a type of roof flashing device used to seal pipe penetrations against leakage.

R-value - see Resistance. $\frac{1}{\text{Btu/hr/ft}^2/\text{F}^\circ}$

SDHW - Solar Domestic Hot Water.

Seasonal Efficiency - the ratio, over an entire heating season, of solar energy collected and used to the solar energy striking the collector.

Selective Surface - a surface that absorbs radiation of one wavelength (for example, sunlight) but emits little radiation of another wavelength (for exmaple, infrared); used as coating for absorber plates.

Shading Coefficient - the ratio of the solar heat gain through a specific glazing system to the total solar heat gain through a single layer of clear double-strength glass.

Solar Constant - the average intensity of solar radiation reaching the earth outside the atmosphere; amounting to two langleys or 1.94 gram-calories per square centimeter, equal to 442.4 $Btu/hr/ft^2$, or 1395 $watts/m^2$.

Solar Fraction - the fraction of a given heating load which is supplied by solar energy.

Solar Radiation (Solar Energy) - electromagnetic radiation emitted by the sun.

Solar Rights (Sun Rights or Solar Access) - a legal issue concerning the right of access to sunlight.

SRCC - Solar Rating and Certification Corporation.

Specific Heat - the quantity of heat, in Btu, needed to raise the temperature of one pound of a material 1^oF.

Stagnation - the condition and temperature which occurs when there is no fluid flow through the solar collectors.

Standby Heat Loss - heat lost through storage tank and piping walls (rate of heat loss differs between standing still and moving).

Stratification - the layering of hot water at the top of a storage tank caused by density differences.

Sun Path Diagram (Solar Window) - a circular projection of the sky vault, similar to a map, that can be used to determine solar positions and to calculate shading.

Tempering Valve - a hot and cold water mixing valve used to reduce hot water temperatures.

Thermal Radiation - electromagnetic radiation emitted by a warm body (see Infrared Radiation).

Thermistor - sensing device which changes its electrical resistance according to temperature. used in the control system to generate input data on collector and storage tank temperatures.

Thermosiphoning - the process that makes water circulate automatically between a warm collector and a cooler storage tank above it (see Gravity Convection).

Thermowell - a sealed hollow tube in which a temperature sensor is mounted so that the sensor can be isolated from a liquid.

Tilt Angle - the angle that a flat collector surface forms with the horizontal plane (see Collector Tilt).

Transfer Fluid - a fluid used to transfer heat from solar collectors to storage.

Transfer Pump - a pump used to fill and pressurize a closed solar collector loop with antifreeze.

Trickle-type Collector - a collector in which the heat transfer fluid flows in open channels on the absorber.

Tube-in-plate Absorber - a metal absorber plate in which the heat transfer fluid flows through passages formed in the plate itself.

Tube-type Collector - a collector in which the heat transfer liquid flows through metal tubes that are fastened to the absorber plate by solder, clamps, or other means (see Collector).

Ultraviolet Radiation - electromagnetic radiation with wavelengths slightly shorter than visible light.

Unglazed Collector - a collector without a cover plate.

Vacuum Breaker - a device used to admit air into a system whenever the system pressure is lower than atmospheric pressure.

Viscosity - a measure of the "thickness" of a fluid and its resistance to flow at any given temperature.

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1982

EDITION

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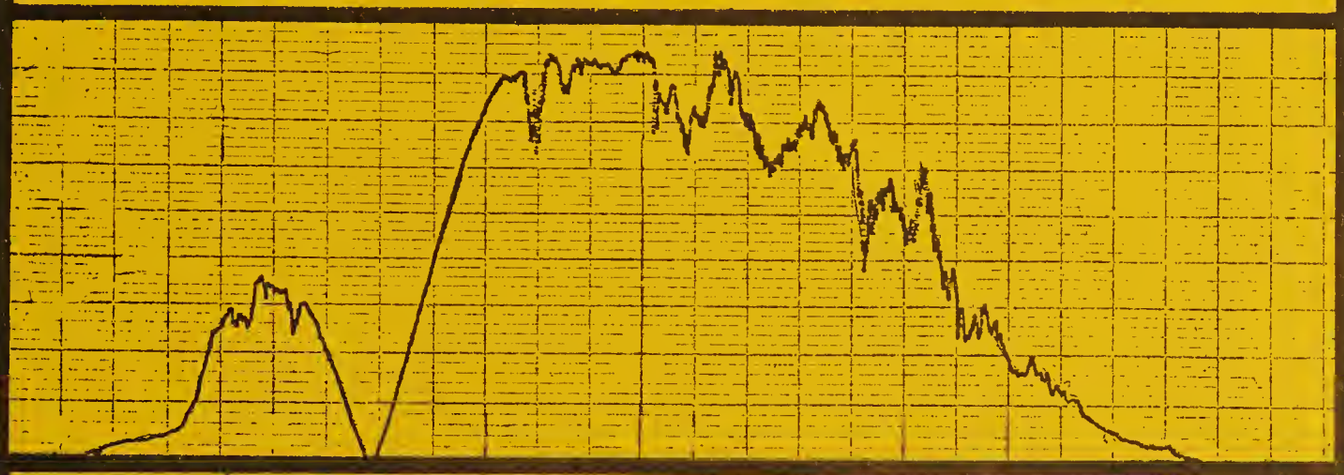

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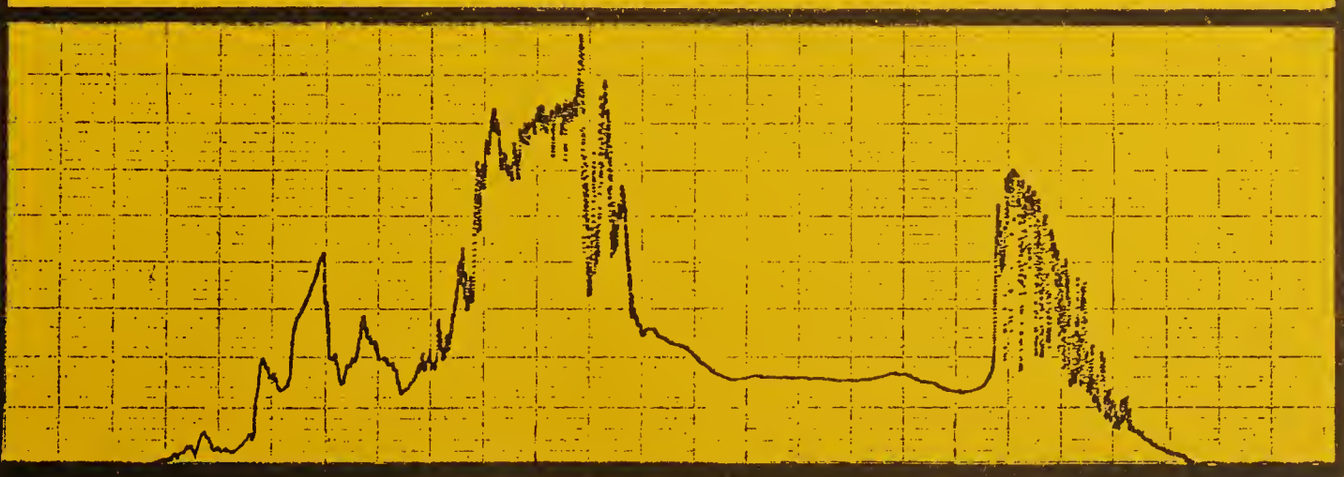

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COVER

Reproduced on the cover are strip chart records of solar radiation. The upper curve illustrates a clear day record and the lower curve was taken on a partially cloudy day. The center chart records the total eclipse on February 26, 1979.

The solar radiation data base contained in this 1982 edition is a summary of 41,600 daily strip charts recorded at 30 Montana stations between January, 1977 and December, 1982.

MONTANA SOLAR DATA MANUAL

December 1982

compiled by

Charless W. Fowlkes, Ph.D., P.E.

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31 Gardner Park Drive
Bozeman, MT 59715

supported by

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32 S. Ewing
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The volunteered assistance of over 50 Montana high school science teachers in maintaining the solar measurement instruments is crucial to the success of this program. Their names are listed on the following pages in this report and their many contributions are gratefully acknowledged.

Several members of the staff at Fowlkes Engineering have contributed to this solar measurement program and the Data Manual. Sharon Kleingartner is acknowledged for her central role in entering (over 50,000 data days) of solar radiation data into the computer for processing. Carlos Lozano, Kellee Crisafulli and Ross Nelson have written numerous computer programs to process and verify the solar data. Pat Sullivan, Jody Martinson and Sharon Kleingartner typed this Manual and made editorial corrections.

The quality of the solar measurement program has benefited from the guidance of expert consultants. John Yellott has provided continuing advice concerning the accuracy of our measuring instruments. Douglas Hoyt of NOAA provided us with computer codes to calculate theoretical clear day solar radiation to improve the accuracy of the data. John Drumheller and Larry Kirkpatrick reviewed the "Handbook of Solar Energy Experiments", a document that was distributed to the high school volunteers. Joe Caprio, Montana State Climatologist, is acknowledged for providing climatological data in this Manual from his extensive files. Mark McKinstry developed and verified the simplified f-chart design procedure. Ray Bahm has recommended methods to identify typical meteorological years from the data base. Roland Hulstrom and Paul Berdahl have contributed to the program. S. Klein has reviewed the Manual and made important suggestions.

STATIONS WITH CONTINUOUS RECORDERS

Location	School	Volunteer	Year
Anaconda	Anaconda H.S.	Mike Knutson Tom Facey	1979–82 1978–79
Billings	Billings Sr. H.S.	Mike Jablin	1977–82
Bozeman	Bozeman Sr. H.S.	Roscoe Montgomery	1977–82
Browning	Browning H.S.	Mr. Marion Salway Jim Prestbo	1981–82 1977–81
Butte	Butte H.S.	John Giop	1978–82
Choteau	Choteau H.S.	Norman Kamrud	1978–82
Colstrip	Colstrip H.S.	Kelly Taylor Dave Bowser	1979–82 1977–79
Dillon	Beaverhead Co. H.S.	William Mular	1977–82
Ennis	Madison Val. Cons. H.S.	Jay Willett Orville Hess	1979–82 1978–79
Fort Benton	Fort Benton H.S.	A. Wm. Kindzerski T. Daniel Gillen	1979–82 1978–79
Glasgow	Glasgow H.S.	Norman Girard	1977–82
Glendive	Dawson Co. H.S.	Richard Lindgren	1978–82
Great Falls	C. M. Russell H.S.	W. Gary Shelden	1977–82
Hamilton	Hamilton H.S.	William Delaney	1977–82
Harlowton	Harlowton H.S.	Scott Dubbs Milo Coladonato	1980–82 1978–80
Havre	Havre H.S.	Marvin Gunnarson Avon Whitehead	1979–82 1977–79
Helena	Helena H.S.	Jim Haslip	1977–82
Jordan	Garfield Co. H.S.	Michael G. Mansfield	1979–82
Kalispell	Flathead H.S.	Gary Freebury	1977–82
Lewistown	Fergus H.S.	Howard Cooper	1977–82
Libby	Libby H.S.	Mike Funk	1977–82
Livingston	Park Sr. H.S.	Ben Williams	1978–82
Miles City	Custer Co. H.S.	Otto Neuhardt John Potts	1977–82 1977–82
Missoula	Hellgate H.S.	Norman Jacobson	1977–82
Plentywood	Plentywood H.S.	Harold Gackle	1978–82
Polson	Polson H.S.	Dan O'Brien Ted Macy	1979–82 1977–79
Red Lodge	Red Lodge H.S.	Bob Holmen	1978–82
Sidney	Sidney Sr. H.S.	Dan Scow Gene Krueger	1980–82 1978–80
Thompson Falls	Thompson Falls	Stuart Kilgore Walter Clark	1980–81 1978–79
West Yellowstone	West Yellowstone H.S.	Scott Carsley Rolf Kuestner	1978–81 1981–82

STATIONS WITH MANUAL RECORDERS

Location	School	Volunteer	Year
Baker	Baker H.S.	Max Mueller	1978-82
Big Timber	Sweetgrass Co. H.S.	Dick Willems	1977-78
Billings	Billings West H.S.	Gerald Raab	1978-82
Boulder	Jefferson H.S.	Mike Myrhow	1978-82
Broadus	Powder River Co. H.S.	Henry Eslinger	1977-81
Chester	Chester H.S.	Marvin Krook	1977-80
Chinook	Chinook H.S.	Gail Swant	1977-78
Circle	Circle H.S.	Robert Fitzgerald	1977-79
Columbus	Columbus H.S.	Waymoth Fitzgerald, Jr.	1977-78
Conrad	Conrad H.S.	James Guthrie	1978-80
Culbertson	Culbertson H.S.	Larry Hyslop	1978-79
Deer Lodge	Powell Co. H.S.	Gary Swant	1977-80
Ekalaka	Carter Co. H.S.	Pat Vaskey Jane Frye	1979-82 1977-79
Eureka	Lincoln Co. H.S.	Neil W. Nelson C. W. Calvert	1979-80 1979
Forsyth	Forsyth H.S.	Eli Urbaniak	1978-79
Great Falls	East Jr. H.S.	John Chase	1979
Hardin	Hardin H.S.	Bonnie Pluhar Roland Croghan	1978 1977-78
Harlem	Harlem H.S.	G. Daniel McNeill	1978-79
Hobson	Hobson H.S.	Rick McIntyre	1977-82
Malta	Malta H.S.	Steve Schumacher Jeffrey Bredeson	1978-82 1977-78
Missoula	Sentinel H.S.	Lyle Leischner Ronald Perrin	1979-82 1978-79
Roundup	Roundup H.S.	Jim Schladweiler	1977-81
Scobey	Scobey H.S.	Dee Black	1978-79
Superior	Superior H.S.	Clark Conrow	1977-79
Townsend	Broadwater Co. H.S.	William Alley	1977-82
Whitefish	Whitefish H.S.	Bruce Tannohill	1978-81
White Sulphur Springs	Wh. Sulph. Spgs. H.S.	Ken Marks Connie Perkins	1978-82 1977-78
Winnett	Winnett H.S.	Frank Witter	1977-78
Wolf Point	Wolf Point H.S.	Arthur Sikkink	1977-82

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Figure 1: Map showing solar radiation network

1 REVIEW OF DATA BASES FOR SOLAR DESIGN

1.1 Introduction

The design of a solar conversion system involves consideration of a number of factors including: solar radiation available at the site, average air temperatures at the site, availability of conventional energy, amount and quality of heat required, economics, taxes, etc. An air temperature data base covering at least 40 years is available for most locations in Montana. Long-term average solar radiation data are, unfortunately, not generally available. This need is addressed by the Montana Solar Data Manual.

The final sections of this Manual contain tables of Solar Radiation measured during the past six years in Montana. Next are tables showing the measured cloudy day statistics for the past six years. Tables of climatological data from National Weather Service records are reproduced in this Manual.

Guidelines for using the solar data to size solar heating systems are included in Appendices. Design topics include heat storage sizing, using f-chart and economic evaluation. Details on the accuracy of the solar measurements are discussed in an Appendix.

1.2 SIMM Solar Data Program

Early in 1977 the SIMM program (Solar Insolation Measurement, Montana) was initiated by Fowlkes Engineering under a grant from the Renewable Alternative Energy Sources Program of the Montana Department of Natural Resources and Conservation. Twenty instruments to measure solar radiation were sited across Montana during 1977 and an additional ten instruments were sited early in 1978. The map on the preceding page, Figure 1, identifies the locations of the stations. The front cover of the Montana Solar Data Manual reproduces three examples of daily solar radiation records; over 50,000 days of data have been collected at this point. The overall goal of this program is to develop a solar radiation data base for use by solar designers. The results of six years of measurements are presented in this Manual. The accuracy of these measurements is thoroughly discussed in Appendix 1.

The solar radiation values presented in this Manual were all measured on a surface tilted 60° up from the horizontal and facing due south. This angle was chosen because it is representative of "typical" solar collector orientation used in Montana for collecting heat in the winter. This data can, consequently, be applied directly to many collector applications which improves the effective accuracy of this data base. The Manual contains procedures to convert this data to other tilt angles. Most of the locations covered in this Manual have no other source of measured solar radiation.

The main limitation to the use of the solar data in this Manual is the relatively short time period (five to six years) represented. There is no simple way at this time to assess how "typical" these values are. The designer can examine the annual data given in the Manual for variability. For the time being, the designer must allow for a reasonable tolerance band in his design due to the absence of better alternatives.

1.3 SOLMET Solar Data

The National Climatic Center, Asheville, North Carolina, has archived historical solar radiation data for two locations in Montana: Great Falls and Glasgow. These data have been recently rehabilitated to an accuracy level of ± 5% and is part of the SOLMET data base. These data are available in tables as well as computer readable tapes. Also available in the SOLMET data base are derived solar radiations for Billings, Cut Bank, Dillon, Helena, Lewistown, Miles City and Missoula. The ersatz data for these locations are estimated from cloud cover observations and their accuracy is about ± 13%.

All SOLMET data are for radiation on a horizontal surface. Solar collector surfaces in Montana will normally be tilted from 45° to 90° up from horizontal, thus the SOLMET data cannot be used directly but must be converted to the appropriate tilt angle. There are several sources of error, when using horizontal solar data, which the designer should recognize: (1) The horizontal radiation data itself will tend to be less accurate in the winter due to the low altitude of the sun relative to a horizontal surface (cosine error) and possible temperature effects on the calibration factor; (2) Reflections from the snow will

affect the total radiation on tilted surfaces (solar collectors), whereas the horizontal data will be relatively less affected. (We have measured reflected radiation in winter on a vertical surface amounting to 10 to 20% of the global radiation.); (3) The calculation methods used to transform horizontal to tilted surface radiation are necessarily approximate and are subjects of continuing discussion in the technical literature.

The factors listed above produce an uncertainty of around $\pm$ 20% in the calculated, tilted surface radiation. The solar designer should take account of the effect of these uncertainties on the sizing and anticipated performance of his system. SOLMET based solar data for Montana are available in the WSUN publication "Montana Solar and Weather Information".

1.4 ASHRAE Clear Day Tables

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has published a number of books and manuals containing a wealth of information on solar energy and solar energy conversion system design. The ASHRAE Handbook of Fundamentals includes a comprehensive review of solar energy facts and references and is required reading. The Handbook of Fundamentals contains extensive tables listing the clear day solar radiation on surfaces oriented at various azimuths and tilt angles. The average radiation however will be considerably less than these values (approximately 30 to 70%) due to clouds and atmospheric filtering.

One ASHRAE table for 48° latitude is reproduced in this Manual. This table lists values for the altitude and azimuth of the sun each month which will help the designer evaluate the amount of shading at his site due to buildings, trees, mountains, etc.. Also included are clear day radiations on surfaces tilted at various angles. This data helps designers calculate peak outputs from active systems and maximum temperatures in passive systems. (For calculating average solar system output the average measured solar radiation should be used.)

2 GUIDE TO THE DATA TABLES

2.1 System of Units

Data in the Montana Solar Data Manual are tabulated using metric units. Earlier solar design books and articles may utilize conventional engineering units but most technical journals now use metric or SI units. The units in this Manual will, therefore, be compatible with current and future technical literature.

The SI unit for energy is the Joule (1 Joule = 1 Watt-second). We have used the kilowatt-hour (kWh) for energy and kilowatt-hour per square meter (kWh/m^2 or KWH/SM) for energy-density. This convention is widely used for solar radiation. A table of conversion factors useful for solar design is included in Appendix V of this Manual. ($317\ BTU\text{-}ft^{-2} = 1\ kWh\text{-}m^{-2}$)

2.2 Solar Data; Overall Monthly Average Table

The solar radiation data have been summarized in two formats: OVERALL MONTHLY AVERAGE and ANNUAL MONTHLY AVERAGE. The primary quantity listed is the Daily Average solar radiation. This quantity is calculated by adding together the measured daily energy density (in kilowatt hours per square meter) for each day in a month and dividing by the number of days in the month.

The Tables of Overall Monthly Averages, Section 3, summarize all radiation data that has been measured at each station since the beginning of the SIMM program. These average values are thus the best current answer to the question, "What is the typical radiation at that station?". If there was considerable missing data, we have inserted an estimated value for overall monthly average. These estimated values are flagged by parentheses.

2.3 Solar Data: Annual Monthly Average Tables

More detailed data is given on a year by year basis in the ANNUAL MONTHLY AVERAGE TABLES, Section 4. An average intensity spectrum or distribution is given for each month. This distribution is given for 12 thresholds of intensity (each 0.1 $kW\text{-}m^{-2}$) as a percentage of the total radiation. This presentation was chosen for statistical reasons

and because the thresholds relate closely to solar-thermal collector performance.

A solar collector will convert only a portion of the incident solar radiation into useful heat; usually around 25% in winters and 50% in summers, based on daily total radiation. A particular collector will have a "threshold value" of radiation intensity above which it can operate efficiently. In a properly operating active system, the "threshold" is the point at which the circulation pump or fan turns on. In a passive system, the "threshold" is the point where the solar heat coming in exceeds the heat loss of the collector. This threshold depends on many factors including the design of the collector (number of glazings, absorptivity and insulation), the storage temperature, and the ambient air temperature and wind velocity. Typical values of this threshold would be 0.1 to 0.2 kW/m^2 for warm weather and 0.2 to 0.4 kW/m^2 for cold weather.

2.3.1 Tilt Correction

The solar radiation values presented in this Manual were all measured on a surface tilted 60° up from the horizontal and facing due south. The user may want to know the expected radiation on a surface at some other tilt angle. To do this conversion, we have included Tables of Monthly Tilt Correction Factors in Section 3. These tables are based on calculations using a sophisticated radiation model. The factors represent a "best" approximation until further data is available.

2.3.2 Missing Data

As you look through the Solar Data Tables you will note that there are some periods for which no data are listed. Data are missing near the beginning of the year in 1977 and 1978 because the program had only recently been funded and the instruments were not installed yet. There have been three cases of stolen or vandalized instruments causing several months of lost data. Some schools had remodeling projects and electrical power outages which interfered with the continuity of the data. There were two cases in which strip chart records became entangled with the janitor's power floor waxer and were lost! Some records were lost because

the recorder ran out of chart paper or malfunctioned and some data were lost in the mail.

Questionable data due to snow-covered transducers or faulty electrical connections have been thrown out. Total lost data due to all causes was about 18% of the current data period of 60,856 data-days. Incomplete data in the solar data tables are flagged with parentheses placed around the daily average. These parentheses indicate that at least one day of data was missing in the averaging period.

2.4 Manual Solar Data

In addition to the 30 continuous solar recording stations there are currently 10 manual solar recording stations. The transducer for the manual stations is essentially the same as the recording stations except that a meter is used in place of the strip chart recorder and the instrument is hand held.

The volunteers at the manual stations are requested to make at least one reading of the solar intensity at 60° tilt, facing south around noon each school day. The readings are sometimes taken by teachers and often by the high school students as a project. The data is recorded on a prepared data form and sent to Fowlkes Engineering each month for processing. Some of the volunteers take and record hourly readings during the school day. No data is taken on weekends or during the summer vacation.

We process the data by averaging all available hourly solar intensity readings each month. These values are plotted against time along with the zero points representing sunrise and sunset. A curve is drawn through these points to produce an "average day" insolation curve. This curve is integrated and the result presented in the Manual Data Tables.

The accuracy of this manual data depends primarily on the care with which the readings were taken and, consequently, cannot be easily determined. The solar designer should compare the Manual Data with nearby continuous recording stations to judge its probable accuracy.

2.5 Cloudy Day Statistics

Tables of the occurrences of cloudy days for each station show the

number of times each year a specified duration of cloudy days occurred. A cloudy day was defined as a day with a total energy density less than 1.5 $kWh/m^2/day$ (473 $BTU/ft^2/day$). It is assumed that most solar collectors would deliver no useful heat on these "cloudy" days. The Tables were compiled for both the total year and the heating season, defined as October 1 to May 21. The number of data-days available are shown in parentheses above each table.

EXAMPLE: To find the number of occurrences of "n" or more cloudy days, add the occurrences of "n" to all occurrences greater than "n". In Kalispell in 1978, for a sample of 353 days, there were 31 single cloudy days and 15 cloudy periods of two or more days. Helena in 1978, for a sample of 353 days, 22 single cloudy days and 11 cloudy periods of two or more days. During the heating season in Helena there were only 18 single cloudy days and 10 periods of two or more cloudy days.

The Cloudy Day Statistics will be useful in determining an optimal thermal storage size for a given system. The designer should note the total number of data-days associated with each table. Stations with significant missing data days will have distorted cloudy day statistics. The designer must also take into account the limited time span (five to six years) of this data.

2.6 Climatological Data

Selected long-term average climatological data taken from National Weather Service records are reproduced in this Manual. For the convenience of the user, the tables are reproduced in metric as well as conventional engineering units. Included are monthly average temperatures; mean daily, maximum daily and minimum daily; monthly record high and record low. The average degree days for each month, base 18.3°C (65°F), are also listed. These data should be useful in estimating the heat requirements of new designs.

SECTION 3

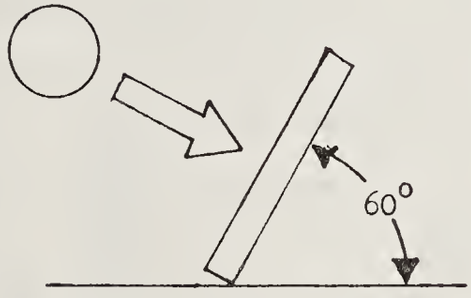
TABLES OF OVERALL MONTHLY AVERAGE RADIATION

a) OVERALL SUMMARY MAP

b) OVERALL MONTHLY AVERAGE RADIATION

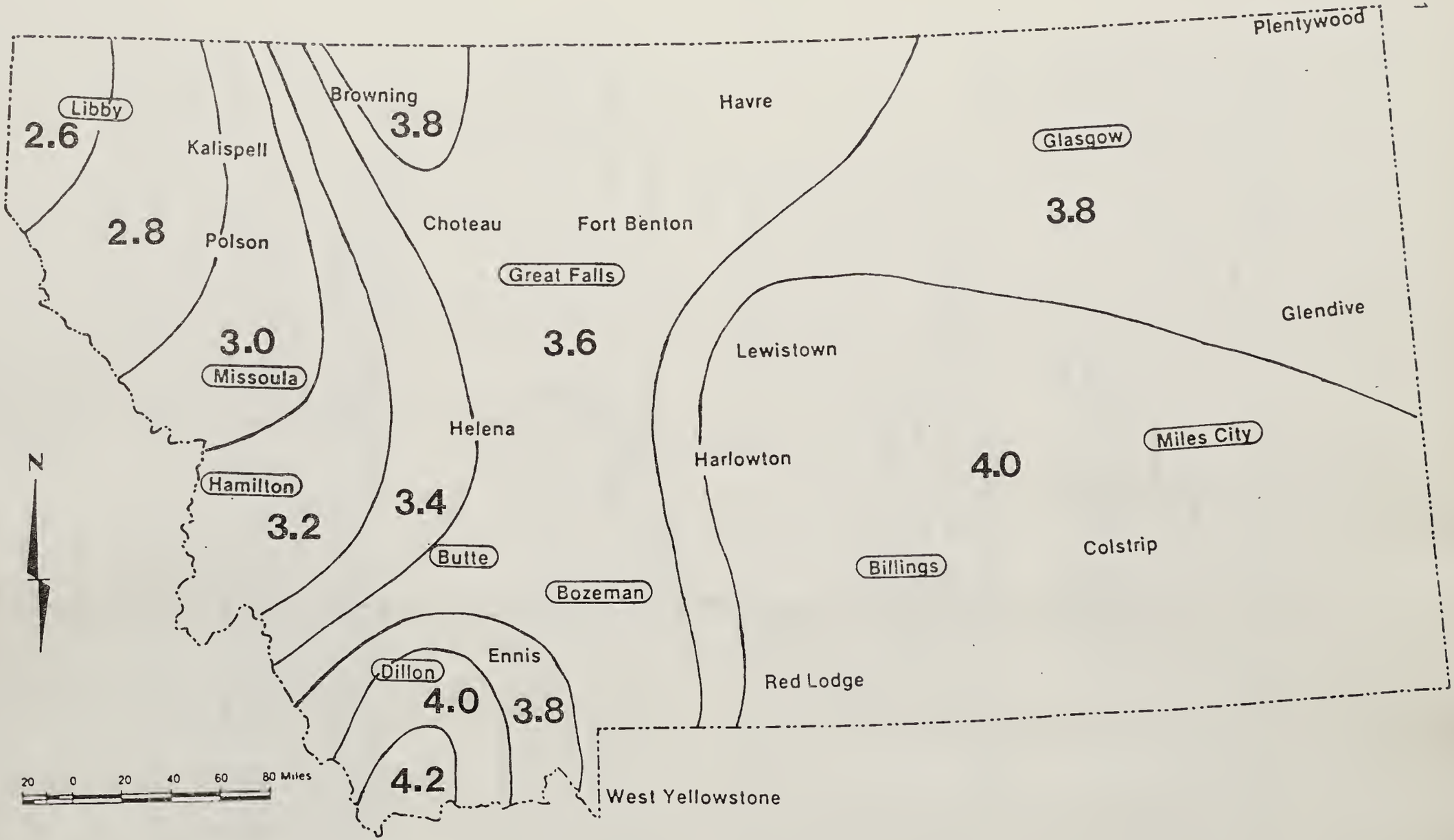
c) TILT CORRECTION TABLE

d) ASHRAE CLEAR DAY TABLE



Note: These Tables summarize the entire solar data base in the form of overall monthly average radiation per day. All data was measured on a 60° tilt; use tilt correction tables to convert data to other tilts.

Units are kilowatt hours per square meter per day. Multiply these values by 317 to get solar radiation in Btu per square foot per day.



Average daily solar radiation, kWh/m^2, during heating season (October through April)

AVERAGE DAILY SOLAR RADIATION 1977-1982 kWh/m^2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	*ACCURACY CLASS
Anaconda	2.8	3.3	4.2	4.3	3.6	4.1	4.7	4.5	4.6	4.1	2.7	2.1	II
Billings	3.3	3.8	4.5	4.6	4.2	4.6	4.8	5.1	5.2	4.4	3.5	2.7	I
Bozeman	2.8	3.5	4.4	4.6	3.9	4.4	5.0	5.1	4.8	4.2	2.9	2.2	I
Browning	(2.9)	4.0	4.5	5.1	4.3	4.6	5.0	(4.9)	4.8	4.3	3.5	2.6	I
Butte	3.2	3.6	4.2	4.6	3.7	4.1	(4.7)	(4.8)	4.6	4.0	3.3	2.4	I
Choteau	3.2	3.5	4.4	4.8	4.2	4.6	5.0	4.9	4.9	4.2	3.1	2.4	I
Colstrip	(3.4)	3.8	4.6	4.6	4.0	4.7	(4.9)	(5.3)	(5.4)	4.4	3.2	2.5	I
Dillon	3.4	4.2	4.7	5.0	4.3	4.7	5.2	5.1	5.2	4.6	3.8	2.7	II
Ennis	(3.1)	4.0	4.4	4.4	3.8	4.4	4.5	4.6	(5.1)	4.1	3.3	2.4	I
Fort Benton	2.6	3.4	4.2	4.3	3.9	4.6	5.2	5.0	4.8	3.9	2.9	2.0	I
Glasgow	3.0	3.9	4.6	4.5	4.5	5.0	5.3	4.9	4.8	4.3	3.1	2.4	II
Glendive	3.1	3.4	4.4	4.5	4.5	4.6	4.8	5.0	5.0	3.7	3.0	2.1	I
Great Falls	2.8	3.6	4.4	4.6	4.2	4.7	5.1	5.0	4.8	4.1	3.2	2.6	I
Hamilton	2.1	3.1	4.0	4.6	3.8	4.4	(4.8)	(4.9)	4.3	4.1	2.7	1.8	II
Harlowton	(3.2)	3.9	4.7	(4.9)	4.0	4.4	(5.0)	(4.9)	5.1	4.2	3.6	2.8	I
Havre	2.9	3.6	4.5	4.5	4.3	4.5	4.6	4.3	4.7	3.9	3.2	2.2	I
Helena	2.7	3.4	4.1	4.4	3.8	4.4	4.5	4.7	5.0	4.3	3.2	2.3	II
Jordan	3.4	3.9	4.8	4.9	4.1	4.6	4.9	(5.3)	(5.2)	4.5	3.3	2.4	III
Kalispell	2.0	2.6	3.8	4.4	4.0	4.6	4.7	4.9	4.5	3.8	1.9	1.4	I
Lewistown	3.4	4.0	4.6	4.8	4.1	4.8	5.0	5.0	4.9	4.4	3.2	2.7	I
Libby	1.8	2.2	3.6	4.3	3.9	4.4	4.7	4.8	4.2	3.2	1.5	1.5	I
Livingston	2.7	(3.3)	4.5	4.5	(4.4)	(5.0)	5.0	5.1	4.8	3.8	3.5	2.0	III
Miles City	3.5	4.0	4.7	4.8	4.1	4.8	4.9	4.9	4.9	4.4	3.1	2.5	I
Missoula	2.1	2.7	3.7	4.0	3.7	4.4	4.5	4.8	4.3	3.8	2.3	1.5	II
Plentywood	3.2	4.0	4.7	4.4	4.2	4.7	5.0	5.1	4.7	4.1	2.9	2.3	II
Polson	1.6	2.5	3.9	4.4	4.1	4.4	4.8	4.9	4.5	3.7	2.0	1.4	I
Red Lodge	3.7	4.0	4.6	4.6	3.8	4.3	4.5	4.6	4.9	4.6	3.7	3.0	II
Sidney	(3.0)	3.6	4.5	4.0	(3.8)	(4.4)	(4.5)	(4.5)	(4.8)	(4.2)	3.3	2.3	II
Thompson Falls	(1.7)	2.2	3.7	4.1	3.6	4.2	(4.7)	(4.4)	(4.6)	(3.8)	(1.8)	(1.4)	II
West Yellowstone	3.0	3.7	4.5	4.8	3.9	4.3	4.7	4.7	5.3	4.8	(2.6)	2.4	II

( ) nominal value

*see Appendix I

RADIATION (kWh/m^2) x 317 = RADIATION (BTU/ft^2)

MONTHLY TILT CORRECTION FACTORS

TABLE FOR STATIONS WEST OF CONTINENTAL DIVIDE

TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	.65	.68	.86	1.02	1.20	1.29	1.26	1.08	.84	.67	.57	.60
10	.75	.78	.93	1.07	1.22	1.30	1.27	1.13	.93	.78	.69	.71
20	.84	.87	.99	1.10	1.22	1.29	1.27	1.15	.99	.86	.79	.81
30	.91	.93	1.02	1.11	1.20	1.25	1.24	1.15	1.03	.93	.87	.88
40	.96	.98	1.04	1.10	1.15	1.19	1.18	1.12	1.04	.98	.94	.94
50	.99	1.00	1.03	1.06	1.09	1.10	1.10	1.07	1.03	1.00	.98	.98
60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
70	.99	.98	.95	.92	.90	.88	.88	.91	.94	.97	.99	.99
80	.95	.93	.88	.82	.79	.75	.75	.79	.86	.93	.97	.97
90	.90	.87	.79	.71	.66	.62	.61	.67	.76	.86	.91	.92
$\bar{K}_t$	.3	.4	.4	.5	.4	.5	.6	.6	.6	.5	.4	.3

TABLE FOR STATIONS EAST OF CONTINENTAL DIVIDE

TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	.47	.56	.75	1.02	1.20	1.29	1.26	1.08	.84	.62	.50	.43
10	.60	.68	.85	1.07	1.23	1.30	1.27	1.13	.93	.74	.63	.57
20	.72	.79	.93	1.10	1.23	1.29	1.27	1.15	.99	.83	.75	.69
30	.82	.88	.98	1.11	1.20	1.25	1.24	1.15	1.03	.91	.84	.80
40	.91	.94	1.01	1.10	1.16	1.19	1.18	1.12	1.04	.96	.92	.89
50	.97	.98	1.02	1.06	1.09	1.10	1.10	1.07	1.03	.99	.97	.96
60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
70	1.01	.99	.96	.92	.89	.88	.88	.91	.94	.98	1.00	1.02
80	.99	.95	.89	.82	.77	.75	.75	.79	.86	.93	.98	1.00
90	.95	.89	.81	.71	.64	.62	.61	.67	.76	.87	.93	.97
$\bar{K}_t$	.5	.6	.6	.5	.5	.5	.6	.6	.6	.6	.5	.5

The factors in these tables when multiplied by the monthly measured solar radiation values (60° tilt) produce an estimate of the solar radiation received by south-facing surfaces at tilt angles other than 60°. These factors are based on calculations by Dr. S. A. Klein.

The tables incorporate typical monthly values of $\bar{K}_t$ for eastern and western portions of Montana. The errors introduced by using these factors should be less than 10%.

Example: The measured radiation in Billings during February was 3.8 kWh/m^2. Estimate the radiation on a vertical (90°) surface. The EAST tilt table factor for February and a tilt of 90° is 0.89. The estimated 90° radiation is thus 3.8 x 0.89 = 3.4 kWh/m^2.

48 Degrees North Latitude

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ 38	48	58	68	90
JAN 21	8	4	3.5	54.6	37	4	17	19	21	22	22
	9	3	11.0	42.6	185	46	120	132	140	145	139
	10	2	16.9	29.4	239	83	190	206	216	220	206
	11	1	20.7	15.1	261	107	231	249	260	263	243
	12		22.0	0.0	267	115	245	264	275	278	255
	SURFACE DAILY TOTALS				1710	596	1360	1478	1550	1578	1478
FEB 21	7	5	2.4	72.2	12	1	3	4	4	4	4
	8	4	11.6	60.5	188	49	95	102	105	106	96
	9	3	19.7	47.7	251	100	178	187	191	190	167
	10	2	26.2	33.3	278	139	240	251	255	251	217
	11	1	30.5	17.2	290	165	278	290	294	288	247
	12		32.0	0.0	293	173	291	304	307	301	258
	SURFACE DAILY TOTALS				2330	1080	1880	1972	2024	1978	1720
MAR 21	7	5	10.0	78.7	153	37	49	49	47	45	35
	8	4	19.5	66.8	236	96	131	132	129	122	96
	9	3	28.2	53.4	270	147	205	207	203	193	152
	10	2	35.4	37.8	287	187	263	266	261	248	195
	11	1	40.3	19.8	295	212	300	303	297	283	223
	12		42.0	0.0	298	220	312	315	309	294	232
	SURFACE DAILY TOTALS				2780	1578	2208	2228	2182	2074	1632
APR 21	6	6	8.6	97.8	108	27	13	9	8	7	5
	7	5	18.6	86.7	205	85	76	69	59	48	21
	8	4	28.5	74.9	247	142	149	141	129	113	69
	9	3	37.8	61.2	268	191	216	208	194	174	115
	10	2	45.8	44.6	280	228	268	260	245	223	152
	11	1	51.5	24.0	286	252	301	294	278	254	177
	12		53.6	0.0	288	260	313	305	289	264	185
	SURFACE DAILY TOTALS				3076	2106	2358	2266	2114	1902	1262
MAY 21	5	7	5.2	114.3	41	9	4	4	4	3	2
	6	6	14.7	103.7	162	61	27	16	15	13	10
	7	5	24.6	93.0	219	118	89	75	60	43	13
	8	4	34.7	81.6	248	171	156	142	123	101	45
	9	3	44.3	68.3	264	217	217	202	182	156	86
	10	2	53.0	51.3	274	252	265	251	229	200	120
	11	1	59.5	28.6	279	274	296	281	258	228	141
	12		62.0	0.0	280	281	306	292	269	238	149
	SURFACE DAILY TOTALS				3254	2482	2418	2234	2010	1728	982
JUN 21	5	7	7.9	116.5	77	21	9	9	8	7	5
	6	6	17.2	106.2	172	74	33	19	18	16	12
	7	5	27.0	95.8	220	129	93	77	59	39	15
	8	4	37.1	84.6	246	181	157	140	119	95	35
	9	3	46.9	71.5	261	225	216	198	175	147	74
	10	2	55.8	54.8	269	259	262	244	220	189	105
	11	1	62.7	31.2	274	280	291	273	248	216	126
	12		65.5	0.0	275	287	301	283	258	225	133
	SURFACE DAILY TOTALS				3312	2626	2420	2204	1950	1644	874
JUL 21	5	7	5.7	114.7	43	10	5	5	4	4	3
	6	6	15.2	104.1	156	62	28	18	16	15	11
	7	5	25.1	93.5	211	118	89	75	59	42	14
	8	4	35.1	82.1	240	171	154	140	121	99	43
	9	3	44.8	68.8	256	215	214	199	178	153	83
	10	2	53.5	51.9	266	250	261	246	224	195	116
	11	1	60.1	29.0	271	272	291	276	253	223	137
	12		62.6	0.0	272	279	301	286	263	232	144
	SURFACE DAILY TOTALS				3158	2474	2385	2200	1974	1694	956

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 38	48	58	68	90
AUG 21	6	6	9.1	98.3	99	28	14	10	9	8	6
	7	5	19.1	87.2	190	85	75	67	58	47	20
	8	4	29.0	75.4	232	141	145	137	125	109	65
	9	3	38.4	61.8	254	189	210	201	187	168	110
	10	2	46.4	45.1	266	225	260	252	237	214	146
	11	1	52.2	24.3	272	248	293	285	268	244	169
	12		54.3	0.0	274	256	304	296	279	255	177
	SURFACE DAILY TOTALS				2898	2086	2300	2200	2046	1836	1208
SEP 21	7	5	10.0	78.7	131	35	44	44	43	40	31
	8	4	19.5	66.8	215	92	124	124	121	115	90
	9	3	28.2	53.4	251	142	196	197	193	183	143
	10	2	35.4	37.8	269	181	251	254	248	236	185
	11	1	40.3	19.8	278	205	287	289	284	269	212
	12		42.0	0.0	280	213	299	302	296	281	221
	SURFACE DAILY TOTALS				2568	1522	2102	2118	2070	1966	1546
OCT 21	7	5	2.0	71.9	4	0	1	1	1	1	1
	8	4	11.2	60.2	165	44	86	91	95	95	87
	9	3	19.3	47.4	233	94	167	176	180	178	157
	10	2	25.7	33.1	262	133	228	239	242	239	207
	11	1	30.0	17.1	274	157	266	277	281	276	237
	12		31.5	0.0	278	166	279	291	294	288	247
	SURFACE DAILY TOTALS				2154	1022	1774	1860	1890	1866	1526
NOV 21	8	4	3.6	54.7	36	5	17	19	21	22	22
	9	3	11.2	42.7	179	46	117	129	137	141	135
	10	2	17.1	29.5	233	83	186	202	212	215	201
	11	1	20.9	15.1	255	107	227	245	255	258	238
	12		22.2	0.0	261	115	241	259	270	272	250
	SURFACE DAILY TOTALS				1668	596	1336	1448	1518	1544	1442
DEC 21	9	3	8.0	40.9	140	27	87	98	105	110	109
	10	2	13.6	28.2	214	63	164	180	192	197	190
	11	1	17.3	14.4	242	86	207	226	239	244	231
	12		18.6	0.0	250	94	222	241	254	260	244
	SURFACE DAILY TOTALS				1444	446	1136	1250	1326	1364	1304

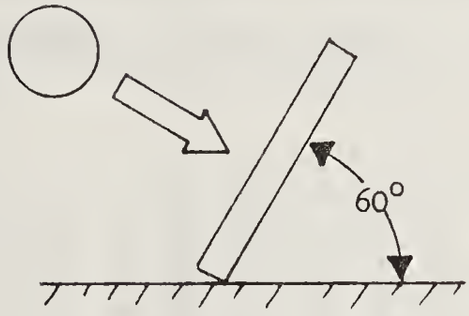
Note: To make these values correspond to the ASHRAE clear day model used in this Manual, multiply by a clearness factor of 1.05 for April through October, and 1.08 for the rest of the year (reflection from snow in winter).

317 BTUH/ft^2 = 1 kW/m^2

SECTION 4

TABLES OF MONTHLY RADIATION BY YEAR

alphabetical by station



Note: The solar radiation values presented in these tables were all measured on a surface tilted 60° up from the horizontal and facing due south.

The solar data tables flag lost data with parentheses placed around the daily average. These parentheses indicate that at least one day of data was missing in the averaging period.

RADIATION (kWh/M2) x 317 = RADIATION (BTU/ft^2)

ANACONDA NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: ANACONDA,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(5.05)	97	93	87	82	78	70	63	54	24	3	0	0
APR	(3.92)	91	78	68	56	45	37	30	21	11	2	0	0
MAY	3.26	83	65	47	39	33	26	21	16	4	0	0	0
JUN	(4.21)	91	83	71	61	50	37	26	12	2	0	0	0
JUL	(4.77)	93	85	79	67	59	50	40	28	12	2	1	0
AUG	(4.40)	95	90	83	74	64	53	48	30	14	0	0	0
SEP	4.19	88	75	69	62	54	46	40	29	21	7	1	0
OCT	(5.31)	97	94	88	83	77	67	59	48	34	16	1	0
NOV	(2.43)	81	60	47	40	35	29	22	16	9	0	0	0
DEC	(2.13)	83	63	54	44	34	24	17	9	1	0	0	0

SOLAR RADIATION DATA for: ANACONDA,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.13)	85	66	59	54	48	41	31	24	16	3	0	0
FEB	(3.00)	91	76	63	50	41	32	25	20	15	7	2	0
MAR	(3.52)	91	70	56	43	37	29	26	20	15	5	0	0
APR	3.97	93	78	67	52	42	34	25	17	12	3	0	0
MAY	4.43	93	82	72	60	48	38	31	18	6	1	0	0
JUN	(4.24)	91	79	69	60	49	35	26	15	4	0	0	0
JUL	4.57	92	83	76	66	56	47	33	23	8	0	0	0
AUG	3.85	88	78	70	58	51	42	30	19	6	1	0	0
SEP	(4.73)	97	91	85	76	64	53	40	31	17	5	0	0
OCT	3.62	89	75	65	59	52	43	36	27	20	6	1	0
NOV	(3.22)	88	76	69	65	58	51	40	28	16	1	0	0
DEC	2.47	88	76	67	61	51	40	26	16	4	2	0	0

SOLAR RADIATION DATA for: ANACONDA,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.77)	88	71	59	51	43	38	32	24	12	1	0	0
FEB	(2.98)	90	79	60	50	42	34	24	19	12	3	1	0
MAR	3.62	94	80	66	55	46	37	24	17	12	4	0	0
APR	(4.54)	93	84	75	67	57	45	36	27	17	2	1	0
MAY	(3.33)	83	69	59	49	38	30	23	17	8	0	0	0
JUN	(3.92)	92	80	67	57	42	30	22	14	4	0	0	0
JUL	(4.61)	94	82	75	66	59	49	36	24	3	0	0	0
AUG	(4.68)	95	88	82	73	63	51	39	25	11	1	0	0
SEP	(4.85)	95	89	83	76	66	59	50	38	24	2	0	0
OCT	4.32	89	80	76	69	64	57	46	36	23	6	0	0
NOV	(2.82)	85	69	61	57	48	42	34	26	15	2	0	0
DEC	2.13	78	67	57	46	36	29	20	13	5	1	0	0

SOLAR RADIATION DATA for: ANACONDA,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.12)	86	77	68	61	52	43	36	29	17	1	0	0
FEB	3.73	92	79	71	63	56	48	41	32	24	14	4	1
MAR	(5.01)	92	80	76	68	62	57	51	44	34	26	10	0
APR	(4.47)	94	83	72	59	52	43	34	24	12	1	0	0
MAY	(3.01)	87	65	48	40	32	25	20	9	1	0	0	0
JUN	(4.64)	93	83	72	65	56	48	35	15	2	0	0	0
JUL	4.68	93	85	79	71	61	51	39	20	2	0	0	0
AUG	4.83	94	87	81	74	65	55	43	28	8	0	0	0
SEP	(4.97)	96	89	82	73	64	56	47	36	20	2	0	0
OCT													
NOV	(2.36)	80	65	58	52	42	30	23	15	7	2	0	0
DEC	1.93	84	64	52	43	32	23	16	9	3	1	0	0

SOLAR RADIATION DATA for: ANACONDA,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.94)	78	56	47	39	32	27	18	15	8	1	0	0
FEB	(3.58)	93	82	73	65	56	44	35	25	13	2	0	0
MAR	(3.63)	93	78	63	52	45	37	28	20	14	8	1	0
APR	(4.88)	94	85	77	68	58	48	40	30	15	2	0	0
MAY	(3.98)	87	73	62	54	46	36	26	15	2	0	0	0
JUN	(3.77)	89	80	66	56	49	35	27	11	1	0	0	0
JUL													
AUG	(4.71)	97	91	81	67	52	39	36	33	26	0	0	0
SEP	3.97	85	73	66	58	52	44	34	25	12	1	0	0
OCT	(2.75)	81	65	56	46	37	32	24	16	13	5	0	0
NOV	2.59	92	80	67	58	49	38	21	13	5	0	0	0
DEC	(1.87)	74	58	50	43	34	26	17	4	0	0	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.38)	86	80	76	71	65	60	51	41	27	7	0	0
MAR	4.04	89	78	71	64	57	48	38	30	17	5	2	1
APR	(5.20)	94	87	81	73	65	58	48	35	16	1	0	0
MAY	4.23	91	82	72	63	53	42	30	14	1	0	0	0
JUN	(4.76)	94	88	82	75	66	54	41	24	2	0	0	0
JUL	4.66	94	88	80	72	62	52	40	21	0	0	0	0
AUG	4.77	94	86	80	73	66	55	43	30	5	0	0	0
SEP	(5.25)	93	87	80	76	70	63	53	40	23	4	0	0
OCT	(4.46)	90	83	76	70	64	56	47	33	17	1	0	0
NOV	(3.73)	90	85	78	69	59	51	39	28	13	1	0	0
DEC	(3.13)	83	69	62	59	53	46	36	27	15	2	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.70	89	66	50	45	36	31	24	18	10	2	0	0
FEB	3.59	91	69	58	54	46	42	36	28	20	11	0	0
MAR	4.92	93	86	78	71	63	52	45	34	23	8	1	0
APR	(3.92)	87	74	64	58	51	41	33	23	11	3	0	0
MAY	3.60	81	66	56	50	45	37	30	19	4	1	0	0
JUN	4.65	93	88	82	75	67	56	44	18	1	0	0	0
JUL	4.20	89	80	72	63	54	46	35	13	0	0	0	0
AUG	5.10	95	90	84	77	70	61	51	35	10	0	0	0
SEP	(4.68)	89	83	76	70	62	55	46	33	18	2	0	0
OCT	(5.07)	97	95	89	84	78	70	61	42	27	4	0	0
NOV	3.39	87	72	60	55	47	39	33	25	16	2	0	0
DEC	2.95	88	78	68	63	52	44	34	23	13	1	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	4.03	95	83	76	71	64	56	46	35	23	4	0	0
FEB	(3.85)	95	86	75	63	54	45	35	25	16	5	0	0
MAR	4.31	92	81	71	64	56	49	41	32	22	10	1	0
APR	(4.12)	90	78	67	58	51	42	33	24	8	0	0	0
MAY	4.26	90	78	70	62	53	42	30	20	4	0	0	0
JUN	(4.70)	94	89	82	73	64	51	35	13	1	0	0	0
JUL	(5.11)	94	89	84	77	69	59	48	30	0	0	0	0
AUG	4.67	92	85	78	68	61	51	41	31	7	0	0	0
SEP	(6.27)	98	96	93	88	83	75	65	52	32	1	0	0
OCT	4.33	90	83	77	71	62	53	44	32	15	0	0	0
NOV	3.84	87	75	70	63	58	52	43	34	16	1	0	0
DEC	2.97	88	79	69	59	51	41	32	19	3	0	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.28)	90	76	67	59	54	44	38	26	15	1	0	0
FEB	3.31	84	74	61	52	45	37	30	25	16	5	0	0
MAR	4.02	90	74	63	56	50	43	36	26	15	5	0	0
APR	(5.17)	95	90	82	74	65	57	49	39	24	2	0	0
MAY	4.73	94	86	79	71	61	49	41	28	9	0	0	0
JUN	4.81	93	88	82	74	67	54	43	21	1	0	0	0
JUL	5.14	95	91	88	82	74	64	51	27	0	0	0	0
AUG	4.72	94	87	78	72	64	53	45	29	6	0	0	0
SEP	4.63	93	85	78	71	64	55	43	32	18	2	0	0
OCT	(4.54)	81	76	72	68	63	57	48	35	18	2	0	0
NOV	2.84	82	66	55	47	38	33	23	16	9	0	0	0
DEC	(1.89)	77	59	51	41	31	24	14	4	1	0	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	4.01	90	86	80	74	68	61	45	32	10	0	0	0
FEB	(3.68)	90	77	69	63	58	50	39	28	18	5	0	0
MAR	(5.45)	91	87	81	76	70	65	52	42	29	10	0	0
APR	(4.80)	96	86	72	67	60	48	41	34	21	5	0	0
MAY	(4.01)	86	74	63	50	41	35	30	20	6	3	1	0
JUN	4.64	92	82	77	70	61	50	38	18	1	0	0	0
JUL	4.89	92	86	80	74	67	57	45	20	0	0	0	0
AUG	5.68	96	94	89	83	76	67	56	35	2	0	0	0
SEP	5.64	91	88	84	79	72	66	57	43	24	1	0	0
OCT	3.91	84	70	60	55	49	45	38	31	21	2	0	0
NOV	(4.07)	90	82	75	70	60	53	45	33	17	0	0	0
DEC	(3.01)	89	77	70	63	56	50	40	27	5	0	0	0

SOLAR RADIATION DATA for: BILLINGS,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.48	84	63	53	45	38	31	25	16	9	2	0	0
FEB	(4.09)	90	83	76	69	63	53	41	31	19	7	0	0
MAR													
APR	(4.52)	92	80	69	62	56	49	40	28	15	1	0	0
MAY	4.10	86	75	65	57	46	38	29	18	4	0	0	0
JUN	(4.14)	91	81	70	61	53	44	30	11	1	0	0	0
JUL	(4.62)	92	85	75	68	59	47	36	17	0	0	0	0
AUG	5.27	96	92	86	80	74	66	54	40	8	0	0	0
SEP	4.55	86	72	67	63	57	52	44	35	21	1	0	0
OCT	4.26	92	85	76	69	60	51	39	28	18	0	0	0
NOV	3.24	81	73	66	60	54	45	35	24	8	0	0	0
DEC	2.28	81	67	55	47	36	26	17	9	0	0	0	0

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.04)	84	67	60	52	42	36	30	23	17	7	0	0
FEB	3.75	91	81	69	59	52	42	35	27	13	2	0	0
MAR	3.45	78	72	63	53	49	40	37	33	27	20	12	8
APR	5.49	96	91	84	75	69	60	52	41	24	3	1	0
MAY	(3.47)	81	70	61	53	41	35	27	19	7	4	4	4
JUN	4.63	92	85	77	69	61	49	34	14	1	0	0	0
JUL	4.80	94	87	78	69	60	48	37	23	3	0	0	0
AUG	(4.78)	94	85	78	71	66	57	46	28	3	1	0	0
SEP	(4.73)	91	81	72	67	60	54	44	37	22	1	0	0
OCT	(4.30)	87	79	71	65	59	51	43	36	23	6	2	1
NOV	(1.99)	73	58	48	38	30	20	16	12	7	2	1	0
DEC	(1.93)	67	53	39	33	29	23	19	16	12	4	1	0

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.53	84	65	51	43	36	32	26	21	14	7	1	0
FEB	(3.81)	95	82	69	59	53	46	40	34	24	17	4	1
MAR	(4.98)	96	91	83	71	65	55	47	38	27	12	2	0
APR	4.02	93	82	65	55	47	36	28	21	12	3	0	0
MAY	(3.75)	89	73	61	51	42	33	24	15	4	0	0	0
JUN	(4.45)	91	83	75	68	60	48	32	12	1	0	0	0
JUL	4.65	94	86	78	69	63	52	39	24	2	0	0	0
AUG	5.00	94	87	77	71	65	56	46	34	12	2	0	0
SEP	4.51	87	78	72	67	62	54	46	38	23	5	1	0
OCT	5.24	95	91	86	80	72	64	55	45	33	5	0	0
NOV	(2.92)	79	66	53	47	42	32	25	19	12	3	0	0
DEC	2.22	68	55	49	44	42	37	31	23	19	3	3	3

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.95)	82	55	48	43	41	36	32	25	19	5	0	0
FEB	3.57	95	79	65	54	48	42	36	27	19	9	2	0
MAR	(4.40)	94	81	66	59	50	43	35	28	23	12	2	0
APR	4.11	94	83	72	59	52	42	32	19	10	1	0	0
MAY	(4.20)	91	80	69	59	50	39	29	19	4	0	0	0
JUN	4.78	94	87	77	69	59	48	37	21	0	0	0	0
JUL	5.32	94	90	86	79	70	61	49	27	1	0	0	0
AUG	(4.77)	93	86	78	72	62	52	40	25	8	1	0	0
SEP	(6.04)	97	94	90	84	78	71	61	48	31	4	0	0
OCT	3.96	88	77	69	62	53	44	37	29	18	1	0	0
NOV	3.95	93	82	74	67	56	50	42	34	20	1	0	0
DEC	2.60	79	66	60	52	42	33	28	19	6	1	0	0

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.03)	83	67	56	50	45	39	32	24	14	3	0	0
FEB	(2.61)	91	66	45	35	30	27	19	13	8	5	1	0
MAR	(4.25)	96	85	73	60	48	43	30	22	17	9	2	0
APR	5.12	95	89	83	75	64	53	45	33	20	4	0	0
MAY	(4.15)	91	80	70	60	52	43	30	19	5	1	0	0
JUN	4.42	92	80	71	63	54	43	30	16	1	0	0	0
JUL	5.02	95	89	82	76	68	58	45	22	0	0	0	0
AUG	(4.91)	94	84	79	71	64	55	45	35	14	1	0	0
SEP	(4.24)	90	80	71	62	54	46	40	30	17	4	0	0
OCT	4.59	84	75	70	66	62	54	47	37	24	2	0	0
NOV	2.58	77	60	51	44	37	30	22	15	9	2	0	0
DEC	(2.07)	79	67	56	45	35	26	18	8	3	0	0	0

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.68	83	75	68	62	57	50	41	29	19	1	0	0
FEB	(3.72)	93	76	62	52	44	40	34	29	20	13	5	0
MAR	5.25	95	85	79	73	65	60	53	43	34	20	1	0
APR	4.33	93	81	73	63	53	44	34	26	16	5	1	0
MAY	3.49	84	69	59	51	43	31	21	14	5	0	0	0
JUN	4.42	94	85	75	68	56	47	33	15	3	1	0	0
JUL	5.24	95	91	85	79	71	62	47	25	2	0	0	0
AUG	5.57	96	92	88	82	74	66	54	37	6	0	0	0
SEP	4.89	90	85	76	71	63	55	44	34	20	1	0	0
OCT	(3.43)	80	68	58	48	42	36	31	25	17	5	1	0
NOV	3.47	81	74	67	61	55	48	39	29	17	2	0	0
DEC	2.20	84	64	54	44	36	31	23	14	5	0	0	0

SOLAR RADIATION DATA for: BOZEMAN,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.06)	80	59	48	33	26	23	16	15	7	1	0	0
FEB	3.55	92	78	65	57	49	41	32	28	18	7	0	0
MAR	3.57	88	73	63	52	42	34	29	21	17	7	0	0
APR	4.68	95	88	78	69	60	53	42	31	14	5	0	0
MAY	3.96	90	78	67	60	49	41	29	16	2	0	0	0
JUN	4.05	93	83	72	61	53	39	26	6	0	0	0	0
JUL	4.84	94	85	79	72	63	52	40	26	3	0	0	0
AUG	5.44	96	92	87	81	73	66	55	40	14	0	0	0
SEP	4.35	88	76	68	62	55	49	41	28	16	0	0	0
OCT	3.86	89	79	73	67	58	47	40	30	18	6	0	0
NOV	2.49	82	65	53	46	38	31	21	15	5	0	0	0
DEC	(2.39)	81	63	55	48	43	37	29	18	2	0	0	0

SOLAR RADIATION DATA for: BROWNING,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR													
APR	(5.77)	97	91	84	78	70	63	54	41	25	8	0	0
MAY	(4.40)	93	82	71	60	47	38	28	19	8	2	1	0
JUN	(4.37)	90	81	70	62	53	44	31	19	3	1	1	1
JUL	4.75	90	83	74	66	56	48	39	24	8	0	0	0
AUG	(3.91)	85	66	53	50	43	39	33	24	6	0	0	0
SEP	(4.11)	79	68	62	57	53	47	38	29	19	1	0	0
OCT	4.04	91	82	73	66	60	51	42	30	15	1	1	1
NOV	(3.04)	90	76	64	53	46	40	32	22	11	0	0	0
DEC	(1.99)	69	46	40	38	34	28	19	13	3	0	0	0

SOLAR RADIATION DATA for: BROWNING,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.04)	89	70	56	48	41	35	29	23	16	5	0	0
FEB	(4.05)	89	79	63	54	47	42	38	32	25	16	1	0
MAR	(4.14)	90	81	72	63	52	45	37	30	21	12	5	1
APR	3.64	87	66	55	48	40	34	28	19	11	4	0	0
MAY	(4.03)	87	71	61	54	44	38	32	23	10	1	0	0
JUN	5.24	94	87	83	77	69	59	45	26	1	0	0	0
JUL	4.65	91	81	73	65	57	51	42	29	5	0	0	0
AUG	(4.77)	93	83	75	68	59	52	42	32	14	3	0	0
SEP	4.90	90	82	76	70	65	58	47	37	27	7	1	0
OCT	4.60	92	84	81	73	65	55	43	33	21	4	0	0
NOV	(4.81)	98	95	90	90	80	71	64	43	12	0	0	0
DEC	(3.55)	98	95	95	81	60	45	10	0	0	0	0	0

SOLAR RADIATION DATA for: BROWNING,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(4.75)	97	88	81	71	64	54	41	29	19	9	1	0
APR	(5.06)	95	86	78	69	60	52	44	36	24	11	2	0
MAY	4.41	90	76	65	55	47	39	32	23	7	1	0	0
JUN	(5.13)	94	86	79	70	61	50	40	26	6	0	0	0
JUL	(4.75)	89	81	74	68	59	51	42	30	3	0	0	0
AUG													
SEP	(5.75)	98	95	90	84	77	69	58	46	28	0	0	0
OCT	3.96	87	78	72	64	55	47	37	28	17	1	0	0
NOV	(3.06)	65	52	48	45	41	36	32	27	18	3	0	0
DEC													

SOLAR RADIATION DATA for: BROWNING,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(4.39)	95	87	76	65	56	45	38	31	21	13	1	0
APR	(5.25)	94	87	80	70	64	52	42	36	21	4	0	0
MAY	(4.46)	86	78	67	60	51	43	36	25	6	0	0	0
JUN	(3.69)	87	73	60	49	34	26	22	13	0	0	0	0
JUL													
AUG													
SEP	(4.75)	92	83	77	70	65	59	50	39	28	0	0	0
OCT	(4.53)	89	83	76	71	64	56	48	37	22	1	0	0
NOV	(3.66)	89	80	73	66	60	53	43	32	14	0	0	0
DEC	(2.25)	80	57	44	35	26	18	13	9	2	0	0	0

SOLAR RADIATION DATA for: BROWNING,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(7.19)	99	97	95	92	86	82	78	67	55	29	0	0
MAR	5.17	93	84	75	72	66	60	52	43	33	18	0	0
APR	(6.01)	97	92	86	79	73	66	56	43	31	15	1	0
MAY	4.06	88	76	64	54	45	35	27	16	5	1	0	0
JUN	(4.70)	91	81	70	62	52	42	31	19	4	0	0	0
JUL	(6.02)	95	93	89	84	78	69	57	36	2	0	0	0
AUG													
SEP	(5.38)	95	88	81	76	67	62	52	41	22	2	0	0
OCT	(3.87)	91	80	74	68	61	51	35	23	11	1	0	0
NOV													
DEC	(3.19)	86	77	71	63	57	46	34	19	0	0	0	0

SOLAR RADIATION DATA for: BROWNING,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.88	80	52	41	33	25	18	13	9	2	0	0	0
FEB	(3.55)	94	84	75	66	54	44	34	25	15	5	0	0
MAR	4.28	95	82	73	63	54	47	39	28	16	4	0	0
APR	5.29	95	88	82	74	67	59	51	40	23	5	1	0
MAY	4.48	89	74	65	57	50	42	34	23	5	0	0	0
JUN	(4.57)	93	83	73	64	54	44	30	14	0	0	0	0
JUL	(5.29)	95	90	84	75	69	58	46	30	3	0	0	0
AUG	(5.22)	95	89	81	73	66	58	46	32	9	1	0	0
SEP	(4.59)	89	75	66	59	55	50	43	32	19	1	0	0
OCT	4.27	90	80	72	64	59	52	44	33	15	1	0	0
NOV	2.78	79	67	57	50	43	37	28	19	6	0	0	0
DEC	2.02	75	60	49	39	34	22	14	3	0	0	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.57)	98	95	88	83	69	53	40	24	15	1	0	0
FEB	3.87	94	82	74	64	55	48	40	30	16	3	0	0
MAR	(3.85)	91	75	65	56	47	38	32	26	17	10	1	0
APR	5.41	97	91	84	74	66	59	50	41	25	2	0	0
MAY	(3.41)	89	70	57	43	31	24	18	13	4	0	0	0
JUN	(4.30)	91	84	76	64	55	43	31	11	1	0	0	0
JUL													
AUG													
SEP	(3.77)	90	75	66	53	48	39	33	24	14	4	0	0
OCT	4.47	95	87	80	71	63	53	44	32	20	3	1	0
NOV	2.01	55	52	50	46	43	39	34	30	26	22	20	20
DEC	2.08	70	46	40	37	34	29	24	17	11	1	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.43)	87	59	45	38	34	27	22	17	11	2	0	0
FEB	3.67	93	76	67	60	53	43	37	28	19	8	1	0
MAR	(4.92)	96	88	81	71	64	56	49	40	28	9	1	0
APR	4.15	94	82	70	60	50	40	30	22	12	6	1	0
MAY	2.30	64	53	43	37	33	29	26	22	17	14	14	14
JUN													
JUL													
AUG													
SEP													
OCT	1.52	41	39	37	37	35	35	34	33	32	27	27	27
NOV	2.84	83	64	56	51	44	38	29	22	13	2	0	0
DEC	2.69	84	64	56	51	45	37	31	24	16	2	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.63	89	74	66	58	51	46	40	34	24	6	0	0
FEB	3.37	93	77	67	57	48	40	30	23	17	10	2	0
MAR	4.56	93	78	65	58	51	44	39	32	26	15	0	0
APR	(3.96)	94	85	71	57	43	31	22	16	9	1	0	0
MAY	(4.22)	92	80	69	57	49	41	30	19	7	0	0	0
JUN	4.22	91	84	74	63	54	41	26	12	2	0	0	0
JUL	(4.57)	93	87	81	75	65	51	36	19	0	0	0	0
AUG													
SEP	(6.01)	98	95	90	85	78	70	62	51	33	3	0	0
OCT	3.87	89	78	71	63	57	51	39	30	18	3	0	0
NOV	3.91	89	79	75	67	60	53	46	36	21	2	0	0
DEC	2.69	88	74	67	58	49	39	32	19	9	1	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.25	91	81	71	64	54	47	35	26	15	5	0	0
FEB	3.22	92	76	64	56	45	34	25	19	13	4	0	0
MAR	3.49	95	82	62	50	39	31	22	15	9	3	0	0
APR	4.62	95	85	74	65	57	47	38	29	17	3	0	0
MAY	3.80	87	75	62	54	47	36	26	17	7	1	0	0
JUN	3.74	92	81	69	56	45	37	24	11	1	0	0	0
JUL	(4.92)	94	90	83	76	67	55	41	21	1	0	0	0
AUG	(5.03)	94	90	84	77	70	60	48	36	16	0	0	0
SEP	4.37	90	81	74	67	60	49	38	31	19	3	0	0
OCT	(4.67)	91	83	75	70	64	57	49	40	28	6	0	0
NOV	3.19	90	81	71	64	52	45	38	27	13	3	0	0
DEC	2.33	74	64	54	47	38	27	19	13	6	0	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.51	89	77	69	62	56	46	37	29	16	1	0	0
FEB	(3.70)	91	78	68	60	54	48	39	29	20	11	1	0
MAR	4.82	91	78	71	65	59	52	46	38	29	17	0	0
APR	4.40	91	81	72	61	54	44	37	27	17	7	1	0
MAY	3.55	87	67	56	47	43	32	23	14	4	1	0	0
JUN	(4.02)	91	78	63	52	43	32	20	14	3	1	0	0
JUL													
AUG													
SEP	(4.32)	94	82	74	63	56	50	40	30	20	2	2	0
OCT	3.62	91	79	70	63	53	46	35	27	18	7	0	0
NOV	(3.45)	82	73	66	61	56	50	42	33	23	4	0	0
DEC	2.24	84	71	59	48	37	29	21	12	7	1	0	0

SOLAR RADIATION DATA for: BUTTE,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.26	81	63	56	46	36	29	24	17	12	6	0	0
FEB	3.88	94	83	73	64	56	48	37	27	17	7	1	0
MAR	(3.48)	92	80	70	55	44	34	27	20	12	4	0	0
APR	4.80	95	87	79	71	62	54	45	33	19	7	0	0
MAY	(3.82)	90	75	66	55	45	37	26	18	2	0	0	0
JUN	(3.92)	91	81	70	59	48	35	22	7	0	0	0	0
JUL	(4.33)	94	86	76	66	52	42	27	13	1	0	0	0
AUG	(4.93)	96	91	85	77	69	60	49	37	14	1	0	0
SEP	4.39	90	76	69	63	57	49	41	31	19	1	0	0
OCT	(3.77)	89	76	67	61	54	48	41	32	24	12	0	0
NOV	2.81	89	74	66	56	47	37	27	18	9	1	0	0
DEC	(2.40)	83	70	59	50	43	36	24	11	2	0	0	0

CHOTEAU NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: CHOTEAU,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(3.97)	86	71	63	55	50	46	40	32	23	13	3	0
APR	(4.24)	92	74	62	53	47	41	35	30	23	12	2	0
MAY	(4.00)	89	73	63	53	46	40	33	27	15	2	0	0
JUN	4.90	95	88	79	71	63	53	41	24	5	1	0	0
JUL	4.54	92	80	73	66	58	51	42	25	5	0	0	0
AUG	(4.91)	94	83	76	68	62	53	43	33	12	2	0	0
SEP	(4.29)	80	72	67	62	55	50	41	32	18	1	0	0
OCT	4.58	93	84	78	71	63	54	42	31	17	1	0	0
NOV	(2.48)	74	54	50	44	37	34	28	22	10	0	0	0
DEC	2.63	87	68	61	54	47	37	29	22	4	0	0	0

SOLAR RADIATION DATA for: CHOTEAU,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.24)	89	70	60	54	48	42	33	26	16	1	0	0
FEB	3.50	94	79	67	57	49	42	35	27	14	5	0	0
MAR	(4.65)	96	86	79	71	63	53	45	35	25	13	0	0
APR	4.43	93	84	73	62	52	44	35	26	15	5	0	0
MAY	4.28	92	80	69	58	46	38	28	17	4	0	0	0
JUN	4.62	94	86	75	63	51	40	28	14	1	0	0	0
JUL	(5.17)	95	90	83	75	65	55	41	26	1	0	0	0
AUG	(4.77)	92	85	80	73	65	55	44	31	12	0	0	0
SEP	5.76	98	95	89	83	76	68	59	47	26	1	0	0
OCT	(4.45)	92	85	79	72	64	56	45	35	24	5	0	0
NOV	3.94	90	82	77	72	62	54	45	35	22	0	0	0
DEC	(2.96)	87	78	70	63	55	46	34	23	6	0	0	0

SOLAR RADIATION DATA for: CHOTEAU,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.15	86	76	69	61	53	45	35	23	10	0	0	0
FEB	(2.97)	86	71	57	49	41	32	25	19	13	3	1	0
MAR	(4.26)	94	81	70	62	53	46	37	31	20	7	1	0
APR	5.23	95	88	78	71	64	54	44	33	19	5	0	0
MAY	4.40	90	81	72	64	55	45	34	20	5	1	0	0
JUN	4.55	93	83	76	68	56	44	31	18	1	0	0	0
JUL	(5.16)	95	89	83	76	68	55	40	21	1	0	0	0
AUG	(4.70)	91	84	80	72	65	54	43	31	18	1	0	0
SEP	4.29	90	79	74	67	61	52	44	34	19	2	0	0
OCT	4.36	90	81	75	69	63	56	45	35	22	2	0	0
NOV	3.09	84	74	67	63	56	48	36	23	7	1	0	0
DEC	1.32	49	39	33	27	21	17	10	6	1	0	0	0

SOLAR RADIATION DATA for: CHOTEAU,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.70	89	81	76	71	64	57	47	33	15	0	0	0
FEB	3.74	87	78	67	59	54	47	40	31	25	10	1	0
MAR	5.09	96	85	75	68	61	57	49	39	29	14	1	0
APR	5.32	96	89	82	73	64	54	45	34	23	8	1	0
MAY	(4.09)	91	77	66	56	47	39	30	18	4	0	0	0
JUN	4.82	94	84	74	64	53	45	34	17	1	0	0	0
JUL	4.90	93	87	80	72	64	51	36	17	1	0	0	0
AUG	(5.36)	95	90	84	79	70	60	48	29	3	0	0	0
SEP	5.62	96	91	86	79	72	64	55	43	25	3	0	0
OCT	3.65	89	74	66	58	51	44	35	25	13	3	0	0
NOV	3.39	85	74	68	61	55	48	40	27	11	0	0	0
DEC	3.09	85	77	69	64	56	48	37	24	1	0	0	0

SOLAR RADIATION DATA for: CHOTEAU,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.30	81	59	53	47	39	32	23	17	4	0	0	0
FEB	3.69	92	82	70	62	54	46	35	27	14	1	0	0
MAR	4.00	92	78	70	61	52	43	35	24	16	4	0	0
APR	4.76	95	87	77	68	59	51	44	33	18	1	0	0
MAY	4.17	87	70	62	56	49	40	32	21	6	0	0	0
JUN	4.32	91	81	73	59	51	40	29	14	1	0	0	0
JUL	5.11	95	89	83	75	67	55	41	22	1	0	0	0
AUG	5.09	94	86	80	73	65	55	45	33	9	0	0	0
SEP	4.28	87	74	66	61	54	47	37	27	14	0	0	0
OCT	4.19	90	82	76	68	62	54	43	30	18	1	0	0
NOV	(2.93)	81	68	62	55	47	39	31	22	6	0	0	0
DEC	2.40	80	70	61	52	40	31	21	10	0	0	0	0

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.31)	91	81	74	66	60	53	46	40	27	11	0	0
MAR	4.68	92	81	75	67	61	53	42	32	24	11	1	0
APR	(5.52)	96	90	84	77	69	61	51	38	22	1	0	0
MAY	(4.70)	91	80	73	66	58	51	38	24	6	1	0	0
JUN	(5.17)	94	90	86	79	68	51	36	9	0	0	0	0
JUL													
AUG													
SEP													
OCT													
NOV													
DEC													

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(4.94)	95	88	78	68	62	55	48	39	26	8	0	0
APR	4.25	86	73	66	57	50	44	36	26	17	3	0	0
MAY	(4.05)	82	71	62	55	50	44	34	20	2	0	0	0
JUN	4.70	93	86	78	71	64	55	41	18	3	0	0	0
JUL	(4.56)	92	83	73	66	57	50	38	20	1	0	0	0
AUG	5.16	93	88	82	75	68	60	50	34	11	0	0	0
SEP	(5.86)	97	94	91	86	79	71	61	45	28	3	0	0
OCT	4.96	92	87	82	76	70	61	52	39	28	5	0	0
NOV	(3.54)	88	75	61	53	44	40	32	26	17	4	0	0
DEC	(2.53)	89	69	56	45	36	31	21	18	10	2	0	0

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.84)	92	82	67	58	49	42	36	27	18	10	1	0
MAR	(4.30)	91	81	70	62	53	46	39	30	17	6	1	0
APR	(3.66)	87	75	62	52	44	33	23	14	7	0	0	0
MAY	(3.18)	87	65	56	48	35	23	15	2	0	0	0	0
JUN	(4.19)	93	84	77	65	56	43	24	6	0	0	0	0
JUL	(4.85)	96	87	81	75	66	58	35	0	0	0	0	0
AUG	(4.22)	95	84	74	59	53	41	26	15	4	0	0	0
SEP	(5.24)	98	93	84	70	63	52	43	25	7	0	0	0
OCT	(4.82)	96	91	86	80	75	70	58	29	17	6	0	0
NOV	(2.66)	84	70	61	49	41	23	12	4	0	0	0	0
DEC	(2.93)	91	79	66	58	48	39	29	14	3	0	0	0

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.85	84	73	67	56	46	38	25	11	1	0	0	0
FEB	(2.79)	78	61	53	45	38	31	25	14	7	3	0	0
MAR	4.15	90	78	68	59	50	41	32	23	15	7	1	0
APR	(4.83)	93	83	74	65	58	52	43	34	21	1	0	0
MAY	4.54	93	84	74	66	56	44	32	18	2	0	0	0
JUN	4.96	93	86	81	76	66	54	38	17	1	0	0	0
JUL	(5.28)	94	89	84	77	71	60	44	23	1	0	0	0
AUG	(6.36)	98	94	91	82	82	74	68	50	36	0	0	0
SEP	(4.92)	92	84	79	72	64	57	47	36	21	3	0	0
OCT	4.65	87	83	77	71	65	59	49	40	26	3	0	0
NOV	3.05	82	73	63	55	45	37	28	20	9	0	0	0
DEC	(1.98)	79	58	46	38	30	21	13	8	3	0	0	0

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.20)	93	82	76	68	64	55	48	39	22	0	0	0
FEB	4.20	94	83	75	67	61	55	47	34	25	11	1	0
MAR	5.55	96	91	84	77	71	64	55	46	36	15	1	0
APR	4.76	94	84	75	65	56	47	38	29	16	4	0	0
MAY	(3.85)	82	72	59	51	45	34	23	12	2	0	0	0
JUN	4.62	93	86	79	68	60	49	36	18	2	0	0	0
JUL	4.90	92	85	78	71	63	54	40	19	0	0	0	0
AUG	(5.56)	96	93	90	85	77	66	53	35	2	0	0	0
SEP	5.66	94	92	89	84	77	70	59	44	21	0	0	0
OCT	(3.79)	83	70	63	56	52	45	38	26	15	2	1	0
NOV	3.88	89	78	73	67	59	52	43	31	15	0	0	0
DEC	3.15	91	78	71	61	51	42	34	24	4	0	0	0

SOLAR RADIATION DATA for: COLSTRIP,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.82	88	69	60	52	44	36	27	18	5	0	0	0
FEB	4.17	88	78	72	65	59	54	46	34	24	4	0	0
MAR	(3.87)	90	76	64	55	47	39	32	24	14	3	0	0
APR	(4.54)	91	83	71	61	53	47	37	27	12	1	0	0
MAY	(3.56)	85	63	53	47	38	29	20	10	2	0	0	0
JUN													
JUL													
AUG													
SEP													
OCT	(3.62)	88	76	67	57	52	41	34	26	17	6	0	0
NOV	3.06	85	73	66	58	48	37	29	18	5	0	0	0
DEC	2.06	78	58	48	39	30	23	16	7	0	0	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.48)	97	90	84	74	70	64	55	40	25	9	0	0
FEB	(4.25)	95	86	78	71	62	51	43	32	21	10	1	0
MAR	(3.94)	91	79	69	59	50	42	33	24	15	6	1	0
APR	(5.41)	97	91	85	76	69	60	52	43	22	5	1	0
MAY	(3.74)	86	76	67	53	45	35	26	16	6	4	3	3
JUN	4.57	92	81	72	63	58	50	38	21	2	0	0	0
JUL	(5.01)	91	84	79	72	64	56	46	32	4	0	0	0
AUG	(4.17)	86	72	67	62	57	47	39	28	7	2	0	0
SEP	4.91	94	86	80	73	64	57	49	38	24	2	0	0
OCT	(4.87)	95	88	81	75	67	57	45	33	21	7	0	0
NOV	3.06	91	74	62	54	46	38	30	22	13	3	0	0
DEC	(2.04)	73	57	50	42	34	27	17	8	2	0	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.39)	83	67	53	45	36	32	22	17	8	1	0	0
FEB	4.37	91	79	73	68	62	56	48	40	29	19	1	0
MAR	(5.35)	96	92	84	79	72	64	56	45	34	17	1	0
APR	(4.64)	94	84	73	62	52	45	38	31	23	8	0	0
MAY	3.87	91	81	68	51	43	35	24	14	5	1	0	0
JUN	5.13	94	90	82	75	67	55	42	22	3	0	0	0
JUL	(4.71)	94	88	80	69	60	49	37	21	2	0	0	0
AUG	(4.72)	95	88	81	68	61	51	38	23	9	0	0	0
SEP	(5.38)	96	92	83	77	71	65	56	41	30	11	1	0
OCT	5.92	98	96	91	86	80	72	63	51	35	14	0	0
NOV	(3.78)	88	76	68	61	57	51	43	36	26	13	0	0
DEC	3.34	91	77	69	65	60	54	44	36	24	6	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.83)	92	77	70	62	58	49	43	34	21	9	0	0
FEB	3.69	95	85	71	60	50	42	32	24	13	6	0	0
MAR	(4.90)	96	87	75	65	56	50	41	34	23	8	0	0
APR	4.94	94	86	77	69	58	51	40	30	19	4	1	0
MAY	(4.72)	94	85	72	64	55	44	33	21	7	0	0	0
JUN	(4.62)	93	86	75	65	54	40	27	16	2	0	0	0
JUL	(5.31)	94	87	81	74	67	58	47	32	3	0	0	0
AUG	5.19	93	85	79	74	68	60	50	37	17	4	0	0
SEP	6.31	97	95	92	87	81	74	66	55	35	3	0	0
OCT	(4.83)	94	88	82	75	66	59	50	40	29	8	1	0
NOV	(4.52)	94	85	77	68	64	56	48	36	25	5	0	0
DEC	3.30	93	83	73	66	59	50	39	24	5	0	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.36	91	79	67	59	52	46	39	28	18	6	0	0
FEB	3.89	93	83	76	69	59	51	39	29	18	7	1	0
MAR	4.17	96	87	74	59	49	41	32	23	14	4	0	0
APR	5.08	93	87	80	73	64	56	48	38	22	3	0	0
MAY	4.31	92	80	69	60	49	41	32	22	5	0	0	0
JUN	(4.57)	93	84	74	63	52	43	31	19	1	0	0	0
JUL	5.38	95	89	84	77	69	60	47	31	4	0	0	0
AUG	(5.57)	97	92	86	80	72	62	51	35	12	0	0	0
SEP	4.85	93	87	80	75	64	54	47	36	23	3	1	0
OCT	(4.58)	88	80	75	72	64	56	46	35	17	1	0	0
NOV	3.19	90	77	68	56	48	41	32	23	14	3	0	0
DEC	(2.60)	88	76	67	58	50	35	27	17	2	0	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.76	87	77	71	65	57	50	42	33	22	1	0	0
FEB	4.55	96	88	79	71	61	56	48	38	28	20	5	1
MAR	5.18	93	82	73	67	62	56	51	42	33	21	2	0
APR	5.17	95	86	76	68	60	51	44	35	28	15	5	0
MAY	(4.00)	92	79	66	54	42	30	22	11	4	0	0	0
JUN	4.77	94	84	76	66	55	44	35	19	2	0	0	0
JUL	5.59	95	92	87	81	74	64	50	31	1	0	0	0
AUG	5.49	96	91	85	80	73	63	52	36	8	0	0	0
SEP	5.17	95	89	80	72	65	56	45	35	18	1	0	0
OCT	4.09	91	81	70	62	56	48	40	31	21	3	0	0
NOV	(5.00)	92	85	83	79	74	67	58	46	31	4	0	0
DEC	(2.46)	86	68	56	47	41	33	22	13	6	0	0	0

SOLAR RADIATION DATA for: DILLON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.73	85	70	60	54	46	34	26	18	12	2	0	0
FEB	4.46	96	90	83	76	68	58	46	36	23	10	0	0
MAR	4.41	96	87	78	69	60	50	40	30	21	6	0	0
APR	4.97	95	88	78	68	59	49	40	28	15	3	0	0
MAY	(4.68)	94	86	74	63	53	43	32	23	6	1	0	0
JUN	4.47	94	87	78	65	57	45	29	9	1	0	0	0
JUL	5.08	95	89	83	74	64	55	43	22	1	0	0	0
AUG	5.54	97	92	87	80	73	65	53	38	13	1	0	0
SEP	(4.76)	95	81	72	66	60	50	42	31	19	4	0	0
OCT	(3.63)	88	72	65	56	48	41	33	25	12	5	0	0
NOV	3.08	92	70	60	53	45	36	27	18	8	2	0	0
DEC	2.93	89	72	67	59	51	40	31	20	4	0	0	0

ENNIS NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: ENNIS,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.90)	95	87	78	68	63	57	54	49	39	27	6	0
MAR	5.19	97	91	84	76	68	59	48	40	27	13	2	0
APR	(3.92)	83	75	67	57	49	44	36	30	23	13	8	6
MAY	3.94	87	77	64	54	43	35	24	17	7	1	1	1
JUN	(3.62)	75	69	63	57	51	44	37	27	12	9	9	9
JUL	(1.95)	54	53	51	49	46	41	35	25	22	21	21	21
AUG													
SEP	(6.42)	99	96	94	85	76	68	63	51	33	0	0	0
OCT	5.34	96	91	84	79	75	66	58	48	33	5	0	0
NOV	(2.64)	87	58	46	41	37	32	26	21	14	3	1	0
DEC	(2.81)	88	71	63	54	48	39	33	25	13	1	0	0

SOLAR RADIATION DATA for: ENNIS,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.48	89	68	60	53	49	43	38	30	21	6	0	0
FEB	(3.42)	91	73	57	51	43	38	32	28	19	11	1	0
MAR	(4.88)	96	89	77	67	58	50	42	35	25	12	1	0
APR	(4.10)	94	83	68	55	47	33	27	17	9	2	0	0
MAY	4.07	90	77	66	56	45	37	26	16	4	0	0	0
JUN	(4.55)	93	84	75	65	57	46	35	17	1	0	0	0
JUL	4.87	94	88	80	73	63	53	40	22	1	0	0	0
AUG	(4.59)	91	83	76	69	62	53	41	30	10	0	0	0
SEP	(6.10)	98	95	90	86	80	73	63	50	33	2	0	0
OCT	4.43	93	85	77	71	65	57	46	35	24	7	0	0
NOV	(4.09)	91	81	75	71	64	57	50	38	27	7	1	0
DEC	2.84	85	71	62	54	51	44	34	26	12	0	0	0

SOLAR RADIATION DATA for: ENNIS,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.35)	87	74	65	59	53	46	40	32	22	7	0	0
FEB	3.27	89	75	59	51	44	35	28	21	13	8	0	0
MAR	(3.86)	93	83	68	59	50	41	32	23	12	6	2	0
APR	(5.31)	96	91	84	78	70	61	51	36	19	4	0	0
MAY	4.01	91	80	69	58	45	37	27	17	4	0	0	0
JUN	4.36	92	80	69	61	54	45	34	16	1	0	0	0
JUL	(4.23)	92	83	75	66	58	48	34	19	2	0	0	0
AUG	4.63	92	84	76	69	62	52	43	32	15	2	0	0
SEP	(4.10)	90	80	72	67	58	49	39	28	18	3	0	0
OCT													
NOV													
DEC													

SOLAR RADIATION DATA for: ENNIS,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.65)	97	91	86	78	69	59	49	40	30	17	4	1
MAR	5.09	95	87	79	71	66	58	48	42	31	20	2	0
APR	4.05	93	81	66	56	47	38	30	22	13	5	3	0
MAY	3.20	86	68	54	42	31	21	11	6	1	0	0	0
JUN	4.04	91	80	67	58	47	39	29	10	1	0	0	0
JUL	4.95	93	87	82	75	66	56	38	16	0	0	0	0
AUG	(4.78)	93	87	81	74	66	57	45	29	9	0	0	0
SEP	4.60	91	81	71	63	55	49	41	32	18	1	0	0
OCT	(3.39)	85	73	64	57	49	42	31	22	14	2	1	0
NOV	3.60	80	72	67	63	59	54	44	34	19	1	0	0
DEC	(2.17)	85	62	47	39	31	23	18	10	5	0	0	0

SOLAR RADIATION DATA for: ENNIS,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.05	79	58	49	40	32	26	21	13	7	3	0	0
FEB	3.92	95	83	75	67	57	47	42	33	24	8	0	0
MAR	3.40	91	78	63	50	43	36	30	23	17	7	0	0
APR	(4.40)	93	82	67	58	50	45	39	27	16	8	0	0
MAY	4.00	94	84	71	58	46	33	22	11	1	0	0	0
JUN	(4.30)	92	82	73	61	51	37	24	13	1	0	0	0
JUL	4.53	93	84	75	68	58	45	33	20	4	0	0	0
AUG	(4.80)	94	87	79	69	60	50	42	29	10	1	0	0
SEP	4.29	89	79	70	60	54	46	38	30	16	2	0	0
OCT	3.43	86	71	63	54	46	41	34	26	15	3	0	0
NOV	2.76	86	70	57	49	40	34	27	17	6	0	0	0
DEC	(1.83)	72	49	38	32	29	23	21	13	3	0	0	0

FORT BENTON NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: FORT BENTON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.88)	94	82	77	66	57	51	45	31	20	6	0	0
MAR	(4.25)	95	84	73	62	55	49	41	30	18	8	0	0
APR	(3.62)	90	69	59	53	47	37	28	17	11	3	0	0
MAY	3.52	84	70	60	51	41	32	26	16	5	0	0	0
JUN	(4.82)	93	87	81	73	62	52	40	13	1	0	0	0
JUL	(5.51)	95	91	82	78	70	63	49	34	3	0	0	0
AUG	5.14	94	87	79	73	66	59	46	32	11	1	0	0
SEP	2.53	57	54	50	47	43	39	35	31	24	16	16	16
OCT	(4.25)	90	83	77	70	62	55	44	33	18	2	0	0
NOV	(2.82)	80	66	52	45	39	34	28	20	6	0	0	0
DEC	(1.77)	85	71	54	47	37	26	9	0	0	0	0	0

SOLAR RADIATION DATA for: FORT BENTON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.70	89	73	64	56	50	41	30	0	0	0	0	0
FEB	(3.15)	91	73	65	59	51	45	34	22	10	0	0	0
MAR	4.21	93	83	70	60	51	45	38	30	19	3	0	0
APR	3.80	89	73	65	57	50	41	32	22	9	1	0	0
MAY	3.81	92	73	62	54	44	34	25	16	3	1	0	0
JUN	4.59	95	88	77	69	59	48	37	21	1	0	0	0
JUL	(4.66)	93	83	73	67	60	52	40	26	1	0	0	0
AUG	(5.05)	96	88	82	75	68	58	48	36	14	1	0	0
SEP	5.63	98	94	91	86	78	69	59	49	29	3	0	0
OCT	3.88	88	81	75	68	61	51	42	33	17	0	0	0
NOV	2.91	89	75	67	61	55	44	33	24	5	0	0	0
DEC	2.16	80	69	62	54	47	36	26	11	0	0	0	0

SOLAR RADIATION DATA for: FORT BENTON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.43)	86	74	66	54	45	34	27	15	3	0	0	0
FEB	(2.86)	84	74	59	46	37	25	18	13	8	3	0	0
MAR	3.77	91	77	68	58	51	42	34	27	19	5	0	0
APR	4.90	95	84	79	70	66	56	46	35	18	3	0	0
MAY	4.48	93	83	76	67	56	46	37	20	0	0	0	0
JUN	4.68	93	84	78	70	61	49	33	17	3	0	0	0
JUL	5.44	95	90	85	78	68	57	44	28	1	0	0	0
AUG	4.83	94	86	78	67	57	49	39	26	10	0	0	0
SEP	4.36	92	81	73	65	58	49	40	31	18	2	0	0
OCT	4.04	81	74	69	66	60	51	40	30	15	0	0	0
NOV	(2.46)	76	63	56	49	42	33	26	20	3	0	0	0
DEC	1.44	63	44	36	29	22	14	10	3	0	0	0	0

SOLAR RADIATION DATA for: FORT BENTON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.13)	83	75	70	64	57	50	41	30	8	0	0	0
FEB	3.47	93	78	71	64	54	47	38	28	17	3	0	0
MAR	4.87	92	79	72	67	62	56	50	40	29	13	1	0
APR	4.58	94	84	74	64	53	43	34	26	15	3	0	0
MAY	3.79	86	70	61	52	45	38	32	20	3	0	0	0
JUN	4.49	91	82	73	65	54	40	27	11	1	0	0	0
JUL	4.98	94	88	81	74	65	53	41	19	1	0	0	0
AUG	4.94	94	88	80	73	65	52	31	10	1	0	0	0
SEP	5.22	95	88	82	77	70	59	50	37	18	0	0	0
OCT	3.72	86	76	68	59	52	44	37	26	14	1	0	0
NOV	3.50	85	76	71	64	57	49	39	24	4	0	0	0
DEC	2.59	82	71	64	57	51	45	34	16	1	0	0	0

SOLAR RADIATION DATA for: FORT BENTON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.21)	84	61	52	43	32	24	17	10	3	0	0	0
FEB	3.59	91	80	66	58	48	38	31	24	16	3	0	0
MAR	4.33	93	79	72	63	54	46	37	28	19	5	0	0
APR	4.82	94	84	75	65	55	48	40	32	20	4	0	0
MAY	(4.11)	82	68	61	55	47	39	32	19	3	0	0	0
JUN	4.58	94	87	78	63	53	43	30	14	1	0	0	0
JUL	(5.28)	95	90	83	76	67	58	43	24	1	0	0	0
AUG	5.24	96	89	82	76	68	58	47	33	5	0	0	0
SEP	4.64	89	78	72	65	57	51	42	31	18	0	0	0
OCT	4.01	89	79	73	66	59	49	42	31	17	0	0	0
NOV	2.82	84	67	60	53	46	40	29	16	3	0	0	0
DEC	2.36	76	63	57	51	41	33	20	9	0	0	0	0

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.43)	93	77	69	62	56	46	35	22	11	0	0	0
FEB	3.94	90	81	73	65	59	49	39	28	14	1	0	0
MAR	4.48	90	82	73	65	54	47	38	29	18	2	0	0
APR	5.51	96	90	84	76	68	58	49	36	15	1	0	0
MAY	(4.62)	87	77	70	64	57	48	35	22	3	0	0	0
JUN	4.54	93	84	75	66	58	45	31	12	1	0	0	0
JUL	(4.87)	94	88	80	71	63	51	40	20	1	0	0	0
AUG	4.24	93	80	69	57	46	37	29	20	7	0	0	0
SEP	3.58	84	68	60	50	43	35	25	19	10	1	0	0
OCT	4.27	91	84	78	71	61	52	41	30	15	1	0	0
NOV	(3.19)	88	77	67	56	49	40	32	20	5	0	0	0
DEC	2.08	81	55	45	38	32	26	21	11	0	0	0	0

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.25)	94	80	63	55	48	41	32	25	13	1	0	0
FEB	3.75	94	79	62	51	43	37	32	27	21	13	5	0
MAR	4.45	95	85	71	60	53	44	38	30	20	6	0	0
APR	(3.77)	82	64	56	50	42	37	31	25	18	7	1	0
MAY	4.28	90	77	64	56	49	40	31	20	5	0	0	0
JUN	(4.95)	93	86	78	70	62	53	41	23	1	0	0	0
JUL	(5.09)	91	83	77	70	64	54	43	27	4	0	0	0
AUG	(5.08)	94	87	80	72	64	55	43	29	9	1	0	0
SEP	(5.07)	86	80	75	71	63	57	49	38	23	6	1	0
OCT	(4.86)	91	85	78	74	66	57	46	37	25	12	1	0
NOV	2.94	86	66	57	52	45	39	33	26	17	9	1	1
DEC	(2.58)	82	64	56	51	46	42	35	26	15	8	5	5

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.51	96	87	77	68	57	49	37	24	7	0	0	0
FEB	3.86	95	78	66	59	52	46	37	29	21	7	0	0
MAR	5.22	97	91	81	73	63	54	46	36	25	8	1	0
APR	(4.16)	88	75	66	55	46	38	30	20	8	1	0	0
MAY	4.14	88	77	68	59	49	38	29	18	2	0	0	0
JUN	(5.38)	95	89	83	76	68	58	45	27	4	0	0	0
JUL	(5.22)	95	89	82	72	65	53	39	22	4	1	0	0
AUG	(5.21)	95	88	81	72	65	56	42	29	9	0	0	0
SEP	(5.73)	96	92	85	80	75	67	57	43	22	1	0	0
OCT	4.41	92	86	79	69	63	55	40	29	16	0	0	0
NOV	2.97	84	70	63	53	46	39	31	19	3	0	0	0
DEC	2.49	82	69	63	54	45	36	23	8	0	0	0	0

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.95)	88	71	64	59	50	41	32	19	7	0	0	0
FEB	3.96	95	78	70	63	57	48	40	30	18	1	1	0
MAR	4.41	96	87	77	67	58	47	35	25	14	2	0	0
APR	5.40	95	88	78	70	64	57	46	35	17	0	0	0
MAY	(5.47)	94	88	81	73	66	56	44	29	7	0	0	0
JUN	5.19	94	86	80	72	62	51	39	21	1	0	0	0
JUL	(5.44)	95	91	85	78	69	59	44	27	2	0	0	0
AUG	4.63	94	86	74	66	58	48	36	25	7	0	0	0
SEP	4.40	94	85	77	68	58	47	35	26	13	0	0	0
OCT	4.33	90	82	75	69	61	53	41	29	15	0	0	0
NOV	(3.22)	90	75	66	60	52	41	31	20	4	0	0	0
DEC	(2.19)	80	60	54	47	40	31	20	9	1	0	0	0

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.95	84	68	62	56	49	44	35	26	12	0	0	0
FEB	3.85	93	86	76	68	57	47	37	30	19	5	0	0
MAR	5.35	93	86	81	75	69	62	54	45	32	14	1	0
APR	(5.08)	95	87	79	70	57	49	36	25	13	1	0	0
MAY	4.28	91	76	66	56	46	34	24	13	2	1	0	0
JUN	(4.82)	91	81	72	64	55	43	31	17	1	0	0	0
JUL	5.58	95	90	84	77	70	59	46	24	1	0	0	0
AUG	(5.60)	96	91	86	79	71	60	47	29	5	1	0	0
SEP	5.35	92	87	81	75	68	60	51	38	14	1	0	0
OCT	3.99	91	79	73	67	57	49	38	27	11	1	0	0
NOV	3.20	81	74	67	59	52	43	34	20	3	0	0	0
DEC	2.29	83	70	59	49	39	31	24	12	1	0	0	0

SOLAR RADIATION DATA for: GLASGOW,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.94)	85	58	43	35	27	19	10	4	0	0	0	0
FEB	3.63	95	84	71	60	50	41	30	15	4	0	0	0
MAR	(3.88)	88	74	62	54	49	43	30	17	6	0	0	0
APR	(3.14)	93	76	54	36	24	12	10	7	4	0	0	0
MAY													
JUN	(5.50)	95	91	86	73	66	49	38	20	6	0	0	0
JUL	(5.68)	96	91	84	76	64	55	44	27	10	1	0	0
AUG													
SEP	(4.53)	89	80	69	62	55	47	40	31	16	1	0	0
OCT	4.04	88	75	68	62	54	49	42	33	17	0	0	0
NOV	3.10	89	78	71	60	51	43	33	21	1	0	0	0
DEC	2.18	86	63	49	41	36	28	20	6	0	0	0	0

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.28)	82	70	59	54	46	40	38	33	25	18	0	0
FEB	4.00	93	81	72	65	58	52	44	34	23	4	0	0
MAR	4.27	89	78	70	63	56	46	35	24	13	2	0	0
APR	5.31	96	90	82	72	64	57	49	38	18	1	0	0
MAY	(4.87)	93	85	78	71	62	53	41	29	2	0	0	0
JUN	4.73	95	87	80	70	59	48	31	13	0	0	0	0
JUL													
AUG	(4.21)	90	78	69	60	49	42	33	24	8	0	0	0
SEP	3.84	82	69	61	56	48	42	34	28	14	1	0	0
OCT	4.13	90	77	70	64	57	51	43	33	17	1	0	0
NOV	(3.03)	91	78	69	62	50	41	31	22	8	0	0	0
DEC	(2.19)	81	56	48	42	34	29	23	15	5	0	0	0

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.04)	92	75	61	51	46	38	32	25	12	0	0	0
FEB	3.23	92	73	54	45	40	36	30	24	15	4	0	0
MAR	(4.09)	93	77	63	57	49	44	32	23	15	6	0	0
APR	3.55	81	66	57	48	41	34	27	19	12	1	0	0
MAY	3.56	83	67	56	48	39	32	21	12	1	0	0	0
JUN	(4.71)	93	85	76	68	59	50	38	16	1	0	0	0
JUL	(4.73)	93	86	78	70	60	49	35	15	1	0	0	0
AUG	(6.21)	97	94	92	87	82	74	66	43	9	0	0	0
SEP	(5.52)	95	91	86	81	75	66	54	39	21	2	0	0
OCT	4.05	91	83	77	71	63	55	44	27	13	0	0	0
NOV	(2.63)	81	57	49	46	37	32	24	16	8	0	0	0
DEC													

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.65)	97	87	80	72	57	47	25	17	9	3	0	0
MAR	(4.02)	96	86	75	65	54	42	36	32	22	10	0	0
APR	(3.58)	83	70	61	52	41	32	22	12	4	0	0	0
MAY	(4.50)	93	83	70	62	54	47	39	29	10	1	0	0
JUN	(4.80)	94	87	78	68	58	48	38	22	2	0	0	0
JUL	(4.77)	94	88	80	73	62	51	37	21	1	0	0	0
AUG	(4.80)	94	86	77	70	60	52	39	26	9	0	0	0
SEP	(5.22)	96	91	86	81	73	66	54	41	21	0	0	0
OCT	(3.13)	94	87	67	51	43	34	13	13	0	0	0	0
NOV													
DEC													

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.47)	93	84	78	68	55	42	32	23	8	0	0	0
FEB	(2.93)	77	62	56	48	42	36	30	24	15	3	0	0
MAR	(4.67)	94	86	78	69	60	50	40	32	22	2	0	0
APR	5.02	94	85	75	66	58	50	42	31	15	0	0	0
MAY	5.36	94	87	82	74	64	54	42	28	4	0	0	0
JUN	(4.90)	91	83	76	71	63	54	42	26	2	0	0	0
JUL	(4.85)	93	85	78	69	60	50	35	21	0	0	0	0
AUG	(4.24)	83	78	72	64	53	43	32	19	0	0	0	0
SEP													
OCT	(3.45)	83	74	69	61	52	41	30	21	3	0	0	0
NOV	3.12	87	78	73	65	57	46	36	23	2	0	0	0
DEC	(1.90)	74	56	49	42	33	26	18	11	0	0	0	0

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.69)	76	63	56	50	47	41	36	23	9	0	0	0
FEB	3.60	92	82	74	66	57	46	39	28	17	5	0	0
MAR	(5.00)	96	88	80	71	63	56	50	41	29	11	0	0
APR	(5.06)	96	89	81	73	63	54	45	34	20	3	0	0
MAY	(5.26)	96	91	83	72	67	60	42	31	3	0	0	0
JUN	4.45	93	86	75	65	54	45	32	18	1	0	0	0
JUL	4.82	95	90	83	76	65	53	40	22	0	0	0	0
AUG	5.26	97	93	87	80	71	60	48	29	1	0	0	0
SEP	5.43	95	91	86	81	75	67	57	44	23	0	0	0
OCT	4.07	91	82	71	64	55	49	40	30	15	1	0	0
NOV	3.22	71	60	54	48	45	39	35	26	10	0	0	0
DEC	(2.42)	81	65	56	51	44	35	27	15	1	0	0	0

SOLAR RADIATION DATA for: GLENDIVE,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(4.41)	96	88	65	48	44	39	34	28	22	0	0	0
APR	4.61	90	79	71	63	56	47	39	26	9	3	0	0
MAY	(3.78)	82	69	54	46	39	31	24	16	2	0	0	0
JUN	(4.69)	89	83	77	66	59	45	32	11	1	0	0	0
JUL	(4.68)	93	85	77	65	53	41	31	15	1	0	0	0
AUG	(5.37)	96	90	83	76	69	60	50	35	5	0	0	0
SEP	4.99	91	81	76	68	63	55	47	35	17	0	0	0
OCT	3.92	79	71	65	59	54	45	37	28	18	3	0	0
NOV	3.11	90	77	68	61	53	43	31	14	3	0	0	0
DEC	2.16	79	60	52	42	33	26	18	5	0	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.51)	74	49	34	29	18	10	0	0	0	0	0	0
FEB	4.01	92	86	76	64	56	47	41	30	17	2	0	0
MAR	4.18	93	80	73	67	57	48	37	26	16	4	0	0
APR	5.23	97	89	82	74	66	57	44	28	14	1	0	0
MAY	4.34	91	78	67	58	49	37	31	20	4	1	0	0
JUN	4.86	94	86	79	70	61	50	37	19	1	0	0	0
JUL	5.09	95	89	80	72	63	53	40	24	4	0	0	0
AUG	4.42	91	79	67	60	52	46	36	26	11	1	0	0
SEP	4.41	88	77	69	63	57	50	42	33	22	2	0	0
OCT	4.06	88	79	72	65	60	52	45	33	19	3	0	0
NOV	(3.24)	92	78	70	62	52	44	33	22	10	1	0	0
DEC	(3.02)	87	76	67	61	53	46	37	26	5	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.02)	90	67	58	53	49	44	36	27	15	3	0	0
FEB	(3.75)	93	83	72	63	54	48	41	34	27	13	3	1
MAR	4.23	92	77	67	59	54	47	41	34	24	12	1	0
APR	4.19	94	77	65	55	48	42	35	28	20	8	3	0
MAY	4.08	89	76	63	55	49	43	36	26	13	3	0	0
JUN	5.01	93	87	80	73	66	57	46	29	6	1	0	0
JUL	4.83	91	81	74	68	62	55	44	30	5	0	0	0
AUG	(5.20)	92	86	80	73	67	58	48	34	14	1	0	0
SEP	4.54	89	79	72	67	59	51	42	33	20	3	0	0
OCT	4.40	90	84	75	67	61	55	46	36	23	2	0	0
NOV	(3.01)	82	66	57	50	44	40	34	25	12	0	0	0
DEC	(2.78)	87	72	63	58	49	43	35	25	10	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.32	91	70	66	58	52	44	35	26	14	1	0	0
FEB	(3.46)	91	76	67	58	48	43	36	26	16	6	1	0
MAR	4.40	92	82	71	62	54	46	40	34	24	9	0	0
APR	3.93	92	77	65	56	46	36	27	18	10	2	0	0
MAY	4.19	91	78	66	56	45	36	27	17	3	0	0	0
JUN	4.74	93	84	76	66	54	41	28	17	3	0	0	0
JUL	5.15	93	85	78	73	64	54	42	27	3	0	0	0
AUG	5.43	95	88	84	78	70	62	51	38	14	1	0	0
SEP	5.87	97	93	89	83	77	70	60	50	33	4	0	0
OCT	4.12	88	80	72	63	56	49	41	33	23	3	0	0
NOV	3.69	87	77	73	68	62	55	44	35	14	0	0	0
DEC	(2.89)	92	82	73	61	49	39	29	18	1	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.94)	92	81	70	57	45	40	29	19	7	0	0	0
FEB	2.87	81	61	50	45	36	32	27	16	9	3	0	0
MAR	(4.14)	93	79	68	60	52	44	34	27	19	7	0	0
APR	5.15	95	87	76	71	63	56	45	35	18	2	0	0
MAY	4.69	90	81	72	65	57	47	38	25	6	0	0	0
JUN	5.04	94	86	79	72	64	52	36	19	4	0	0	0
JUL	5.34	95	90	83	76	67	55	42	22	1	0	0	0
AUG	4.74	94	84	74	66	57	48	38	25	10	0	0	0
SEP	4.38	92	81	72	65	59	50	39	27	13	2	0	0
OCT	4.17	81	75	68	63	57	48	40	27	15	0	0	0
NOV	2.89	81	70	62	53	47	37	28	19	4	0	0	0
DEC	(1.49)	55	40	33	26	18	13	10	5	0	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.76	87	79	74	66	58	49	41	31	13	1	0	0
FEB	3.60	88	75	67	59	51	44	38	32	19	8	0	0
MAR	5.27	93	83	76	67	63	58	52	45	33	20	0	0
APR	4.70	95	81	72	63	58	46	40	31	19	6	0	0
MAY	3.68	88	70	63	53	47	36	25	16	3	0	0	0
JUN	4.52	93	83	74	63	51	38	28	12	2	0	0	0
JUL	5.05	95	88	82	73	66	55	42	20	1	0	0	0
AUG	5.35	94	88	83	77	71	62	51	38	5	0	0	0
SEP	5.35	96	90	85	79	71	60	51	41	22	2	0	0
OCT	3.71	89	76	71	62	54	44	33	25	14	2	0	0
NOV	3.49	86	74	70	63	56	50	41	30	12	0	0	0
DEC	(2.83)	84	75	66	60	49	43	34	22	2	0	0	0

SOLAR RADIATION DATA for: GREAT FALLS,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.51	83	64	55	50	40	32	26	15	5	0	0	0
FEB	3.95	94	84	75	63	56	48	38	28	18	5	0	0
MAR	4.13	89	78	70	61	52	42	34	27	18	6	0	0
APR	4.59	93	83	71	60	55	48	41	31	15	1	0	0
MAY	3.92	83	67	59	52	44	36	28	19	3	0	0	0
JUN	4.49	94	83	74	63	54	45	28	12	1	0	0	0
JUL	5.37	96	90	85	77	68	58	45	24	1	0	0	0
AUG	5.19	95	89	82	76	68	59	46	31	5	0	0	0
SEP	4.51	88	78	70	64	57	52	43	32	15	1	0	0
OCT	4.12	89	80	72	67	60	53	43	33	20	0	0	0
NOV	2.99	81	68	62	54	47	40	31	20	6	0	0	0
DEC	(2.48)	81	68	60	53	45	35	26	12	0	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR	(3.54)	92	77	66	56	44	33	27	19	14	8	1	0
APR	(5.24)	96	85	79	73	64	55	46	35	24	8	1	0
MAY	(3.81)	92	76	60	48	37	29	23	15	8	1	0	0
JUN	(4.52)	93	82	72	63	53	44	32	14	0	0	0	0
JUL	(4.16)	93	82	73	62	49	41	29	12	1	0	0	0
AUG													
SEP	(3.17)	89	69	57	47	35	28	21	15	7	3	0	0
OCT	4.13	92	80	72	64	58	50	37	27	17	3	0	0
NOV	(2.45)	83	62	53	47	39	34	29	18	12	1	0	0
DEC	(1.53)	65	44	30	26	22	19	15	10	1	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.50)	68	32	23	18	14	12	10	7	3	1	0	0
FEB	(3.04)	89	68	59	52	46	39	32	26	15	5	2	0
MAR	(4.41)	96	86	76	68	57	48	38	30	15	3	0	0
APR	(4.16)	93	85	75	60	50	41	30	19	10	2	0	0
MAY	(3.10)	88	65	49	40	30	24	15	7	3	1	0	0
JUN													
JUL													
AUG	(4.33)	85	77	69	64	51	43	32	18	3	0	0	0
SEP	(3.55)	87	69	60	52	48	39	29	16	6	0	0	0
OCT	(5.14)	94	89	83	78	71	65	55	44	21	4	0	0
NOV	2.18	70	48	44	36	32	26	17	12	3	0	0	0
DEC	(2.37)	80	60	51	42	37	31	25	17	4	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.15)	85	72	63	55	49	43	37	27	10	0	0	0
FEB	2.47	83	67	49	38	31	23	16	12	8	3	0	0
MAR	4.55	92	80	72	65	58	50	42	34	25	12	0	0
APR	3.98	92	82	68	55	45	36	24	18	9	1	0	0
MAY	4.65	94	83	72	61	51	41	33	24	12	0	0	0
JUN	(4.72)	90	82	73	65	56	46	35	22	3	0	0	0
JUL	5.01	92	86	80	72	65	53	41	25	3	0	0	0
AUG	(6.42)	96	93	90	85	80	71	59	45	10	0	0	0
SEP	(5.77)	98	94	90	84	77	69	58	46	26	1	0	0
OCT	3.87	88	74	67	59	52	46	39	30	20	3	0	0
NOV	(3.30)	88	79	73	68	55	47	38	24	5	0	0	0
DEC	1.78	73	58	49	37	29	21	13	5	0	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.75)	89	69	58	48	44	38	28	21	11	1	0	0
FEB	2.91	90	72	61	54	45	36	29	20	12	7	0	0
MAR	(3.32)	95	77	62	52	39	29	19	14	7	3	0	0
APR	4.44	93	84	76	67	56	47	37	29	10	3	0	0
MAY	(4.22)	89	79	68	60	50	43	33	23	3	0	0	0
JUN	4.33	94	83	74	64	53	42	31	15	1	0	0	0
JUL	(4.98)	96	90	85	78	68	56	43	24	0	0	0	0
AUG	(5.07)	97	91	84	77	67	55	45	30	6	0	0	0
SEP	(4.07)	93	82	73	63	53	45	35	28	16	0	0	0
OCT	4.58	91	86	81	75	67	59	49	38	23	3	0	0
NOV	(2.79)	86	72	63	55	46	39	28	20	8	1	0	0
DEC	(2.09)	73	59	48	44	37	28	20	13	3	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.49	52	43	36	27	20	14	8	6	2	0	0	0
FEB	(4.16)	88	78	74	67	60	53	46	39	28	9	0	0
MAR	4.76	93	79	72	65	60	55	47	38	26	16	1	0
APR	4.69	96	87	76	65	57	46	38	29	19	6	1	0
MAY	(3.58)	92	72	58	42	32	25	19	13	3	0	0	0
JUN	4.34	93	84	72	61	51	38	27	13	1	0	0	0
JUL	5.34	96	91	87	79	71	60	46	24	0	0	0	0
AUG	5.47	96	92	87	80	74	64	52	33	2	0	0	0
SEP	5.05	96	90	81	73	66	57	46	36	18	1	0	0
OCT	3.57	82	69	62	57	50	43	35	28	14	2	0	0
NOV	2.88	78	69	60	52	43	37	29	22	8	1	0	0
DEC	(1.44)	66	45	33	26	19	14	11	6	1	0	0	0

SOLAR RADIATION DATA for: HAMILTON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.69	77	51	36	27	19	14	12	9	5	1	0	0
FEB	(3.34)	89	75	64	56	49	43	35	25	16	3	0	0
MAR	3.25	93	76	62	50	38	28	21	14	7	3	0	0
APR	4.81	94	83	77	69	61	52	41	28	18	6	1	0
MAY	4.09	91	76	65	59	49	38	28	14	2	0	0	0
JUN	(4.66)	94	85	77	67	56	46	34	13	0	0	0	0
JUL	(5.05)	95	88	80	73	63	53	41	24	2	0	0	0
AUG	(5.64)	97	93	87	80	72	65	53	37	14	2	0	0
SEP	4.55	93	79	69	63	57	50	43	32	18	1	0	0
OCT	(3.35)	88	73	63	55	44	36	30	22	14	2	0	0
NOV	2.85	90	73	64	51	44	37	29	18	5	1	0	0
DEC	(1.96)	78	57	48	40	32	23	17	7	0	0	0	0

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.22)	95	90	84	71	54	49	49	23	13	0	0	0
FEB	4.34	90	83	76	65	57	51	45	37	28	13	2	2
MAR	4.60	95	85	77	71	61	53	46	33	22	9	0	0
APR	5.58	96	87	81	74	68	63	53	40	26	6	0	0
MAY	(4.28)	90	78	68	59	50	40	31	23	10	0	0	0
JUN	(5.30)	95	90	85	81	74	61	45	24	0	0	0	0
JUL	(4.75)	94	86	76	68	60	52	42	26	7	0	0	0
AUG	4.72	92	83	75	67	59	50	41	31	16	1	0	0
SEP	4.85	93	84	78	73	64	55	44	36	22	7	1	0
OCT	(4.46)	88	80	73	67	61	53	46	34	19	2	0	0
NOV	(2.57)	87	64	50	41	34	28	21	12	6	0	0	0
DEC	2.79	80	63	56	50	44	39	30	22	14	0	0	0

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.17)	90	69	57	53	47	40	33	24	15	2	0	0
FEB	3.64	95	79	65	54	48	39	31	23	15	6	0	0
MAR	5.01	93	84	78	70	63	57	47	37	26	9	0	0
APR	3.98	88	74	63	52	45	38	33	22	15	6	1	0
MAY	2.88	70	58	49	43	37	32	27	23	17	11	10	10
JUN	2.60	58	55	52	49	45	41	36	27	18	17	17	17
JUL	4.50	89	80	72	64	56	47	38	21	1	0	0	0
AUG	5.01	94	88	81	73	65	57	47	31	11	2	1	1
SEP	(4.62)	87	77	73	65	59	52	45	36	23	4	0	0
OCT													
NOV													
DEC													

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.88)	97	95	88	80	69	62	54	43	28	5	1	0
FEB	3.90	92	84	73	65	56	47	36	26	16	7	0	0
MAR	(4.87)	92	80	71	66	59	53	43	33	25	15	0	0
APR													
MAY	(4.21)	91	76	66	57	48	38	28	19	7	1	0	0
JUN	4.69	93	86	77	67	57	48	35	19	1	0	0	0
JUL	(5.56)	94	91	86	80	73	62	44	19	0	0	0	0
AUG	(4.57)	91	80	75	68	61	52	39	31	16	0	0	0
SEP	5.99	98	95	90	83	77	70	61	48	32	6	0	0
OCT	(4.43)	92	85	76	70	61	53	44	32	17	1	0	0
NOV	3.68	88	76	68	61	56	47	40	29	14	1	0	0
DEC	(3.12)	90	82	70	63	54	43	33	22	4	0	0	0

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.27	87	73	64	58	51	46	36	27	12	0	0	0
FEB	(3.21)	87	73	60	49	40	32	23	16	12	4	0	0
MAR													
APR	(5.41)	96	90	85	80	67	61	52	39	17	0	0	0
MAY	4.53	92	83	74	65	57	46	34	22	7	1	0	0
JUN	(4.48)	92	82	73	66	58	48	37	18	2	0	0	0
JUL	5.21	95	90	85	78	69	58	46	27	2	0	0	0
AUG	(4.71)	94	85	77	69	58	49	41	30	11	2	0	0
SEP	(5.01)	96	91	85	78	72	59	53	34	22	0	0	0
OCT	4.43	88	77	71	66	57	49	39	32	20	0	0	0
NOV	3.45	87	73	65	58	51	44	35	25	10	0	0	0
DEC	(2.56)	89	72	59	51	38	31	21	14	1	0	0	0

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.92)	72	51	43	37	33	19	19	12	0	0	0	0
FEB	4.28	95	82	77	72	61	51	45	36	25	12	0	0
MAR													
APR	(4.51)	93	83	74	65	55	44	31	23	13	1	0	0
MAY	3.42	82	69	58	47	37	28	19	9	1	0	0	0
JUN	(4.22)	91	70	64	57	53	39	32	19	3	0	0	0
JUL													
AUG													
SEP	(5.60)	92	88	84	78	71	64	55	45	27	0	0	0
OCT	(3.75)	87	73	68	60	51	45	36	30	19	2	0	0
NOV	(4.63)	92	88	83	78	72	62	51	39	19	0	0	0
DEC	2.96	88	75	68	60	49	41	31	19	3	0	0	0

SOLAR RADIATION DATA for: HARLOWTON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.69)	91	66	54	49	40	36	28	17	7	0	0	0
FEB	(4.28)	96	88	80	73	60	51	40	27	21	9	1	0
MAR	4.30	91	79	71	62	54	47	37	29	19	9	0	0
APR	(5.10)	96	89	80	68	60	53	45	33	21	5	0	0
MAY	4.12	90	76	65	55	44	35	26	17	6	1	0	0
JUN	(3.58)	91	72	62	49	38	29	23	8	0	0	0	0
JUL													
AUG	(5.63)	96	93	88	82	74	65	55	40	11	0	0	0
SEP	4.48	87	75	67	64	57	50	42	32	18	0	0	0
OCT	(4.49)	90	84	78	75	67	61	54	40	22	2	0	0
NOV	3.31	84	71	65	56	50	44	35	24	11	0	0	0
DEC	2.67	83	70	63	56	47	40	26	12	2	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.17)	94	85	77	67	60	54	45	37	21	8	0	0
MAR	(4.60)	94	85	74	66	58	53	45	34	22	10	1	0
APR	(5.49)	96	91	84	78	70	62	50	35	16	2	0	0
MAY	(4.57)	89	81	75	68	59	50	36	24	7	1	0	0
JUN	(4.68)	92	82	75	68	60	49	36	20	1	0	0	0
JUL	4.66	91	83	76	68	60	49	37	21	2	0	0	0
AUG	(4.42)	90	77	67	62	52	45	37	26	7	0	0	0
SEP	4.05	81	71	65	58	52	47	39	31	22	4	1	0
OCT	4.38	92	87	79	71	62	51	41	33	19	1	0	0
NOV	(3.25)	85	69	63	58	51	44	38	30	15	0	0	0
DEC	(2.38)	81	66	57	51	44	34	24	14	3	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.75)	91	67	54	44	37	31	24	18	11	2	0	0
FEB	3.73	95	81	68	60	50	41	35	25	15	3	0	0
MAR	4.33	95	86	76	65	55	45	32	22	14	3	0	0
APR	3.40	80	61	51	45	40	33	27	18	9	2	0	0
MAY	3.02	69	62	55	48	43	37	31	23	15	10	9	9
JUN	4.73	92	86	81	73	65	53	40	20	1	0	0	0
JUL	(4.42)	89	83	75	69	59	50	37	23	3	0	0	0
AUG	(3.41)	90	77	70	70	70	62	53	53	28	0	0	0
SEP	4.58	87	80	73	66	59	51	41	33	22	5	0	0
OCT	4.53	89	80	75	70	63	55	48	38	22	3	1	0
NOV	2.82	86	64	57	49	42	35	26	18	10	1	0	0
DEC	2.11	78	58	50	43	35	27	19	10	1	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.51)	94	87	80	73	60	48	34	18	4	0	0	0
FEB	(3.16)	93	70	56	51	45	35	26	18	8	2	0	0
MAR	4.88	94	86	80	71	63	54	46	36	25	8	1	0
APR	(3.73)	88	74	65	55	46	37	28	16	5	0	0	0
MAY	(4.50)	93	84	75	64	54	44	34	24	10	0	0	0
JUN													
JUL													
AUG	(4.17)	89	74	65	59	51	43	36	27	1	0	0	0
SEP	5.39	97	93	88	81	74	65	54	40	18	1	0	0
OCT	4.07	91	82	74	66	61	51	39	29	14	0	0	0
NOV	3.47	83	69	64	57	53	47	39	26	7	0	0	0
DEC	(2.44)	84	73	63	54	43	32	24	13	1	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.75	82	69	63	54	43	35	28	17	6	0	0	0
FEB	(3.17)	81	69	61	54	48	39	28	20	9	0	0	0
MAR	(4.24)	94	80	71	62	55	45	34	27	17	6	1	0
APR	5.29	94	84	80	74	68	61	51	37	19	2	0	0
MAY	(5.18)	94	89	83	75	66	55	42	28	7	0	0	0
JUN	4.38	91	84	78	70	60	45	31	10	2	0	0	0
JUL	3.80	93	86	77	63	47	13	4	2	0	0	0	0
AUG	(3.63)	91	82	70	58	41	23	8	5	3	0	0	0
SEP	(4.35)	90	84	75	68	58	48	41	28	17	3	0	0
OCT	(2.63)	75	60	47	43	36	29	20	11	4	0	0	0
NOV	2.67	77	65	57	48	38	33	26	19	7	0	0	0
DEC	(1.79)	73	49	41	36	28	24	17	10	1	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.68	86	78	71	65	60	52	42	29	7	0	0	0
FEB	3.71	94	82	73	65	55	43	35	22	15	2	0	0
MAR	5.23	92	82	75	71	67	58	51	43	32	14	1	0
APR	4.84	94	86	77	66	56	48	39	29	18	6	1	0
MAY	3.98	83	70	63	57	49	39	28	16	4	0	0	0
JUN	4.25	87	78	71	63	54	45	30	18	3	0	0	0
JUL	5.11	94	89	84	77	69	59	45	27	2	0	0	0
AUG	(5.24)	94	89	86	77	70	59	46	32	4	0	0	0
SEP	5.44	94	89	85	79	73	62	50	39	22	1	0	0
OCT	3.84	83	75	68	60	53	47	38	28	16	1	0	0
NOV	3.61	86	80	73	66	59	50	40	25	5	0	0	0
DEC	2.51	83	67	57	52	42	35	28	14	2	0	0	0

SOLAR RADIATION DATA for: HAVRE,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.08	87	61	49	41	32	23	15	8	1	0	0	0
FEB	(3.42)	91	78	68	53	43	35	29	24	12	1	0	0
MAR	4.13	90	75	66	58	52	45	37	30	18	5	0	0
APR	(4.76)	95	86	77	67	59	50	40	27	12	2	0	0
MAY	(4.02)	81	68	63	57	50	40	32	22	2	0	0	0
JUN	(4.62)	91	82	75	66	56	46	31	19	2	0	0	0
JUL	(5.25)	94	89	84	77	72	61	50	29	2	0	0	0
AUG	5.41	94	87	83	77	71	62	52	36	7	0	0	0
SEP	(4.42)	83	73	68	61	55	50	41	33	18	1	0	0
OCT	4.07	91	80	73	65	57	49	39	27	11	0	0	0
NOV	(3.07)	90	74	68	62	55	45	38	24	6	0	0	0
DEC	2.00	76	60	52	43	34	22	11	3	0	0	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.34)	85	63	53	43	36	27	22	13	8	3	1	1
FEB	(4.17)	91	83	76	67	58	50	42	32	18	7	0	0
MAR	(3.81)	93	78	64	53	46	37	29	22	13	5	0	0
APR	(5.11)	96	90	83	74	66	56	46	31	14	0	0	0
MAY	(4.07)	92	76	68	57	49	35	26	19	6	1	0	0
JUN	(4.35)	86	74	69	62	56	47	37	23	4	3	3	3
JUL	(5.07)	94	88	83	73	65	55	41	26	2	0	0	0
AUG	(4.74)	92	84	75	66	59	49	42	31	8	0	0	0
SEP	4.54	92	81	72	64	57	50	41	31	16	4	0	0
OCT	4.45	95	88	79	72	64	55	44	29	14	2	0	0
NOV	(3.11)	84	71	62	56	50	42	36	27	14	2	0	0
DEC	(2.29)	80	61	53	44	34	27	22	18	12	2	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.64)	87	63	47	40	36	31	25	18	11	5	1	0
FEB	(3.53)	94	82	66	56	46	37	30	24	14	8	1	0
MAR	(4.85)	96	88	77	69	59	51	43	33	18	9	0	0
APR	4.60	92	85	74	64	56	45	37	26	19	7	0	0
MAY	(3.56)	85	68	54	43	35	28	19	12	4	0	0	0
JUN	4.86	93	86	77	69	60	51	40	21	1	0	0	0
JUL	4.82	93	86	78	71	63	53	42	27	2	0	0	0
AUG	5.08	95	88	79	73	64	55	45	32	11	1	0	0
SEP	4.57	86	76	70	64	57	51	43	34	23	10	1	0
OCT	5.10	96	91	84	77	68	61	50	38	23	5	0	0
NOV	2.76	82	64	54	46	40	33	27	18	12	3	0	0
DEC	2.60	82	66	54	47	40	34	29	22	8	0	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.64)	92	77	67	62	56	48	39	30	18	2	0	0
FEB	(3.41)	93	77	65	55	45	37	28	20	13	6	2	0
MAR	4.67	95	85	74	64	54	47	39	31	20	7	0	0
APR	(4.34)	93	83	72	63	54	43	32	21	11	3	0	0
MAY	(4.43)	94	81	69	59	48	36	28	16	9	0	0	0
JUN	4.57	94	88	78	67	55	44	30	16	2	0	0	0
JUL	(4.84)	94	87	81	73	64	54	42	20	1	0	0	0
AUG	4.84	93	83	75	68	62	54	46	29	7	0	0	0
SEP	5.70	97	93	88	80	73	64	55	42	23	1	0	0
OCT	(4.05)	88	78	73	66	60	51	39	26	16	4	0	0
NOV	(3.62)	87	77	70	64	58	50	42	30	14	1	0	0
DEC	2.71	87	76	66	56	48	39	31	19	8	1	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.08)	92	76	67	58	50	38	31	22	13	2	0	0
FEB	2.91	83	69	55	45	36	31	25	17	9	4	0	0
MAR	(3.86)	93	82	67	55	46	37	31	21	14	6	0	0
APR	(5.11)	92	86	79	72	65	56	45	31	14	2	0	0
MAY	4.02	88	79	69	60	51	39	28	13	3	0	0	0
JUN	(3.37)	88	76	65	50	38	27	15	4	0	0	0	0
JUL	(3.02)	89	78	62	47	35	25	15	5	0	0	0	0
AUG	(3.88)	93	85	69	60	48	32	24	14	2	0	0	0
SEP	(5.06)	99	94	86	78	69	60	48	29	15	0	0	0
OCT	(4.47)	88	79	72	68	62	54	45	34	18	0	0	0
NOV	(3.09)	85	75	67	61	56	47	40	28	14	2	0	0
DEC	1.81	70	55	43	37	30	24	16	6	1	0	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.40)	85	73	66	61	55	48	39	31	17	1	0	0
FEB	(3.90)	89	78	68	60	53	46	40	33	27	15	3	0
MAR	(5.21)	92	80	72	68	64	56	51	43	32	16	3	0
APR	(4.11)	92	80	69	61	47	40	28	20	13	1	0	0
MAY	(3.43)	82	67	57	50	41	32	23	11	2	0	0	0
JUN	4.43	94	84	74	63	51	41	29	11	1	0	0	0
JUL	(4.96)	94	89	84	79	70	59	43	16	1	0	0	0
AUG	5.02	95	91	86	80	70	62	47	30	4	0	0	0
SEP	5.09	95	90	80	72	63	55	46	35	22	2	0	0
OCT	3.53	87	73	63	56	48	40	32	21	10	1	0	0
NOV	(3.74)	82	74	68	64	57	50	43	32	17	1	0	0
DEC	(2.22)	83	69	59	47	38	32	24	14	4	0	0	0

SOLAR RADIATION DATA for: HELENA,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.30	56	40	34	24	17	10	4	0	0	0	0	0
FEB	2.98	92	80	68	57	40	24	11	4	0	0	0	0
MAR	(2.13)	84	59	44	30	20	9	2	0	0	0	0	0
APR	3.47	91	78	65	54	41	28	10	0	0	0	0	0
MAY	(3.38)	89	75	65	49	35	21	5	0	0	0	0	0
JUN													
JUL													
AUG													
SEP													
OCT													
NOV													
DEC													

JORDAN NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: JORDAN,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB													
MAR													
APR													
MAY	(4.12)	85	71	63	56	50	43	30	20	5	1	0	0
JUN	4.98	94	89	84	74	65	53	41	22	3	0	0	0
JUL	5.14	91	86	79	72	63	52	39	24	1	0	0	0
AUG	5.55	95	90	83	78	71	61	52	37	13	0	0	0
SEP	(4.91)	85	79	76	71	65	58	48	37	18	1	0	0
OCT	4.31	91	82	75	68	59	51	39	27	10	0	0	0
NOV	(2.38)	71	53	47	40	34	28	22	11	1	0	0	0
DEC	(2.09)	85	63	53	43	37	26	10	2	0	0	0	0

SOLAR RADIATION DATA for: JORDAN,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.09)	94	80	71	62	54	43	30	13	1	0	0	0
FEB	(3.36)	92	81	68	58	52	43	35	23	13	5	0	0
MAR	(4.21)	90	79	68	57	51	45	36	29	17	6	0	0
APR	4.17	87	74	62	53	45	38	30	22	14	5	0	0
MAY	(4.42)	93	83	70	61	50	41	31	19	11	1	0	0
JUN													
JUL													
AUG	(5.09)	95	89	83	74	67	56	43	26	2	0	0	0
SEP	6.03	97	94	89	85	78	70	60	47	26	1	0	0
OCT	(4.42)	91	84	78	73	67	60	50	37	14	0	0	0
NOV	3.34	86	76	68	62	56	48	38	25	3	0	0	0
DEC	(2.42)	79	65	57	50	42	34	24	18	0	0	0	0

SOLAR RADIATION DATA for: JORDAN,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.36)	86	74	65	60	55	46	36	24	14	1	0	0
FEB	3.69	86	72	63	56	49	43	39	30	21	5	0	0
MAR	4.64	94	87	78	70	61	50	42	30	19	6	0	0
APR	5.49	95	86	79	73	66	60	50	39	21	1	0	0
MAY	(5.06)	93	85	80	73	67	56	44	29	3	0	0	0
JUN	4.52	92	82	77	71	64	53	39	16	1	0	0	0
JUL	(4.84)	94	88	85	80	73	63	45	17	0	0	0	0
AUG	(5.81)	97	94	89	84	76	68	58	41	20	0	0	0
SEP	4.68	88	82	77	71	63	52	43	33	19	3	0	0
OCT	4.92	87	81	74	70	66	60	53	43	24	3	0	0
NOV	3.77	88	80	73	66	61	54	44	33	15	0	0	0
DEC	(2.27)	81	65	56	47	40	33	22	10	0	0	0	0

SOLAR RADIATION DATA for: JORDAN,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.19)	86	82	77	73	69	62	53	42	27	0	0	0
FEB	4.19	91	81	71	63	56	51	45	36	26	16	1	0
MAR	5.88	94	89	83	77	70	66	58	48	39	22	0	0
APR	5.00	95	89	79	69	61	52	40	28	14	1	0	0
MAY	3.76	83	70	60	50	42	32	21	9	1	0	0	0
JUN	4.22	92	83	73	64	57	45	28	2	0	0	0	0
JUL	4.84	93	87	83	75	66	54	39	15	0	0	0	0
AUG	5.62	96	92	89	83	77	66	54	33	5	0	0	0
SEP	5.60	91	88	84	79	73	66	57	45	21	0	0	0
OCT	4.47	90	81	72	67	61	55	46	36	20	1	0	0
NOV	(3.86)	80	76	71	65	58	52	44	36	20	0	0	0
DEC	2.92	85	76	67	61	54	45	35	22	4	0	0	0

SOLAR RADIATION DATA for: JORDAN,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.12	94	78	64	57	51	43	34	24	15	5	0	0
FEB	4.72	97	91	84	77	71	62	53	44	29	6	1	0
MAR	4.36	88	77	67	60	53	47	40	35	24	8	1	0
APR	4.78	94	86	77	69	61	50	39	33	18	3	0	0
MAY	3.38	79	63	54	46	39	32	21	12	1	0	0	0
JUN	4.35	93	80	75	69	56	44	32	14	2	0	0	0
JUL	4.74	93	82	77	72	65	53	40	18	1	0	0	0
AUG	5.47	95	89	85	79	74	64	54	36	8	0	0	0
SEP	(4.65)	88	77	69	64	56	48	40	32	18	0	0	0
OCT	4.32	89	79	71	66	59	53	46	36	21	1	0	0
NOV	3.15	85	73	66	59	51	42	34	24	13	0	0	0
DEC	2.16	82	58	47	42	32	25	19	9	2	0	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(2.80)	84	63	51	42	35	27	22	17	10	0	0	0
MAR	(2.99)	85	65	53	43	33	28	21	15	9	2	0	0
APR	5.01	95	87	77	70	61	50	40	32	20	0	0	0
MAY	3.89	91	76	65	55	42	34	23	15	5	0	0	0
JUN	(4.73)	93	81	72	63	54	46	33	17	1	0	0	0
JUL	(4.04)	87	75	62	51	41	33	23	11	3	0	0	0
AUG	4.75	90	80	73	68	60	54	45	33	13	1	0	0
SEP	(3.66)	83	72	63	54	46	38	31	22	12	1	0	0
OCT	(3.87)	91	78	71	63	58	49	38	28	12	0	0	0
NOV	(2.49)	74	55	52	48	43	35	28	19	9	1	0	0
DEC	(1.82)	63	46	34	31	25	18	15	11	6	0	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.55	77	30	25	21	15	12	9	7	6	3	0	0
FEB	2.78	89	65	52	43	37	32	26	20	14	4	1	0
MAR	4.34	94	77	66	58	50	44	38	33	24	13	6	0
APR	3.77	93	74	58	47	39	32	25	18	11	4	1	0
MAY	3.60	88	72	57	47	40	31	25	19	11	4	1	1
JUN	4.86	93	84	76	66	59	49	38	27	5	0	0	0
JUL	(4.73)	94	84	77	69	62	51	39	18	1	0	0	0
AUG	4.24	91	80	70	62	51	44	31	16	1	0	0	0
SEP	3.59	88	74	64	56	48	38	32	25	14	2	0	0
OCT	(4.69)	96	89	83	76	68	59	48	35	17	2	0	0
NOV	2.33	75	51	46	41	34	29	25	20	10	2	0	0
DEC	(1.99)	74	46	41	36	29	24	20	15	11	2	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.68)	81	60	51	47	43	38	33	26	11	2	1	0
FEB	1.92	82	48	30	23	19	13	10	8	4	2	1	0
MAR	4.49	94	83	72	64	56	50	44	33	22	4	0	0
APR	(4.11)	91	78	67	59	51	43	34	23	14	4	1	0
MAY	(4.41)	91	80	67	60	51	42	34	24	6	0	0	0
JUN	4.87	93	86	76	66	57	48	37	23	3	0	0	0
JUL	5.19	95	87	79	72	63	53	44	30	5	0	0	0
AUG	5.44	95	88	83	77	70	61	52	40	22	2	0	0
SEP	6.11	97	94	89	85	78	72	63	52	37	12	1	0
OCT	(3.44)	79	70	62	56	47	41	33	25	13	0	0	0
NOV	1.75	50	41	34	28	24	20	14	8	2	0	0	0
DEC	.73	34	22	17	12	10	8	6	4	2	0	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.88)	78	63	56	48	41	34	27	19	12	2	0	0
FEB	(2.40)	78	52	44	37	32	25	18	12	8	4	0	0
MAR	3.54	90	75	60	52	44	36	27	20	14	6	1	0
APR	(4.67)	87	79	72	64	57	49	40	27	12	0	0	0
MAY	4.08	88	76	62	52	45	38	30	18	5	0	0	0
JUN	(4.23)	90	80	67	58	47	34	22	10	0	0	0	0
JUL	4.79	91	83	75	68	60	50	40	22	2	0	0	0
AUG	4.81	93	84	76	69	61	51	40	29	11	0	0	0
SEP	4.24	91	79	73	66	58	51	38	27	14	2	0	0
OCT	4.16	91	82	77	69	62	52	41	33	18	0	0	0
NOV	1.67	71	59	48	39	32	26	19	8	3	0	0	0
DEC	1.10	43	32	24	22	16	12	9	5	0	0	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(.98)	36	26	23	21	14	11	8	5	4	1	0	0
FEB	2.56	78	53	46	41	37	30	26	19	15	7	3	0
MAR	4.51	92	80	72	64	57	51	39	31	22	10	0	0
APR	4.21	92	77	66	57	47	41	34	22	14	5	1	0
MAY	(3.87)	93	79	67	51	41	30	25	14	7	2	0	0
JUN	(4.23)	93	76	63	51	43	35	27	11	0	0	0	0
JUL	5.08	94	87	78	70	61	53	42	21	1	0	0	0
AUG	(5.34)	95	89	84	76	66	57	44	31	9	1	0	0
SEP	5.00	93	86	81	75	67	58	49	38	22	3	0	0
OCT	(3.29)	86	75	64	53	41	33	27	20	10	2	0	0
NOV	(1.46)	64	53	42	33	22	14	9	4	2	1	0	0
DEC	1.66	67	51	46	40	31	24	19	12	1	0	0	0

SOLAR RADIATION DATA for: KALISPELL,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.75	68	47	39	32	29	23	16	12	7	3	1	0
FEB	(2.92)	84	64	51	45	39	34	28	21	14	5	0	0
MAR	3.12	85	69	58	48	39	32	23	18	11	4	0	0
APR	4.42	94	84	74	62	53	42	31	25	12	2	0	0
MAY	4.15	90	75	67	57	48	39	28	18	2	1	0	0
JUN	4.42	93	83	75	68	58	49	33	17	0	0	0	0
JUL	4.61	92	81	74	64	56	45	36	21	2	0	0	0
AUG	4.84	94	88	79	70	61	50	40	26	5	1	0	0
SEP	4.78	88	81	74	67	59	52	41	32	17	2	0	0
OCT	3.47	83	74	65	56	50	41	32	24	10	3	0	0
NOV	1.68	60	45	36	31	26	20	14	8	3	1	0	0
DEC	1.17	56	36	28	21	16	10	6	0	0	0	0	0

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.16)	93	73	66	60	53	49	43	36	24	8	0	0
MAR	4.47	96	87	76	63	56	48	39	31	19	7	0	0
APR	(5.44)	96	89	82	75	67	57	49	38	20	3	0	0
MAY	4.42	90	77	69	61	51	43	35	25	6	0	0	0
JUN	5.07	95	88	81	71	62	52	40	23	3	0	0	0
JUL	(4.73)	93	85	76	70	60	49	40	27	5	0	0	0
AUG	4.25	89	80	72	62	51	41	35	26	9	0	0	0
SEP	(4.70)	91	80	73	66	59	51	44	33	18	3	0	0
OCT	4.38	94	84	78	68	62	54	44	32	14	1	0	0
NOV	(2.97)	89	70	63	53	46	38	26	18	6	0	0	0
DEC	(2.85)	90	68	59	53	46	38	31	20	8	0	0	0

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.71)	88	60	53	49	42	39	31	22	13	1	0	0
FEB	(3.66)	94	75	61	53	47	43	37	30	18	11	1	0
MAR	5.12	96	89	80	70	62	55	48	38	26	11	0	0
APR	(3.95)	89	76	64	54	45	36	29	24	15	6	0	0
MAY	(4.00)	87	76	64	56	45	36	26	19	6	1	0	0
JUN	4.89	91	85	78	71	63	53	42	24	4	1	0	0
JUL	(4.41)	93	80	72	63	52	44	35	19	2	0	0	0
AUG													
SEP	(4.49)	88	77	69	63	57	51	44	35	21	1	0	0
OCT	(4.91)	94	87	80	71	64	56	48	37	22	4	0	0
NOV	(2.89)	88	63	54	43	34	26	19	13	9	0	0	0
DEC	(2.36)	71	60	54	48	43	36	32	28	17	11	10	10

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.86)	94	78	70	66	62	53	43	31	9	2	0	0
FEB	(4.07)	94	85	77	69	60	50	40	29	15	5	0	0
MAR	(4.50)	92	81	72	62	56	47	40	33	25	15	0	0
APR	4.15	91	77	66	57	49	40	31	22	13	3	1	0
MAY	(4.15)	92	77	64	55	43	36	28	18	7	0	0	0
JUN	(4.96)	93	87	78	69	61	52	40	25	2	0	0	0
JUL	(5.32)	94	87	81	74	67	59	46	29	3	0	0	0
AUG	5.10	95	89	78	72	63	52	41	28	10	1	0	0
SEP	6.15	98	95	90	86	79	71	61	49	32	2	0	0
OCT	4.39	92	83	78	70	64	55	45	32	19	3	0	0
NOV	3.64	89	77	66	61	53	45	40	31	18	1	1	0
DEC	(3.06)	84	73	64	56	50	42	36	26	11	0	0	0

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.07	89	71	63	55	45	40	30	22	13	2	0	0
FEB	3.94	88	75	66	61	54	46	40	29	18	7	0	0
MAR	3.98	94	81	64	55	49	38	30	23	15	7	0	0
APR	(5.52)	97	92	87	79	68	59	49	39	22	5	1	0
MAY	4.79	95	88	80	70	59	46	35	22	4	0	0	0
JUN	4.64	92	81	74	67	60	50	38	22	1	0	0	0
JUL	5.17	95	90	82	75	65	54	41	26	1	0	0	0
AUG	4.93	95	88	79	71	64	54	41	29	10	1	0	0
SEP	4.26	90	78	69	59	52	44	35	27	17	4	1	0
OCT	4.48	85	74	68	63	59	54	46	38	25	4	0	0
NOV	3.29	82	70	64	57	51	43	37	28	14	0	0	0
DEC	(2.09)	75	58	48	42	34	29	20	13	2	0	0	0

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	4.35	89	82	78	74	69	61	54	41	25	2	0	0
FEB	4.09	94	81	71	64	59	50	41	33	24	10	0	0
MAR	5.58	95	87	78	73	67	60	54	44	35	20	1	0
APR	4.55	93	85	75	66	56	44	32	22	15	4	0	0
MAY	3.94	79	69	60	52	45	39	33	22	8	1	0	0
JUN	4.78	93	85	77	66	56	46	35	21	6	0	0	0
JUL	5.25	94	88	83	76	69	61	49	32	4	0	0	0
AUG	(5.13)	96	89	85	81	74	65	53	36	7	0	0	0
SEP	5.50	93	87	82	78	71	65	58	45	28	3	1	0
OCT	(4.18)	90	78	69	64	60	52	45	36	23	7	0	0
NOV	3.86	87	80	73	63	58	51	41	31	17	0	0	0
DEC	2.83	86	76	68	59	50	39	31	20	4	0	0	0

SOLAR RADIATION DATA for: LEWISTON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.99)	92	75	66	60	53	37	28	20	10	0	0	0
FEB	(4.12)	94	84	69	63	56	48	42	34	26	13	1	0
MAR	4.17	91	76	66	59	52	45	39	30	20	8	0	0
APR	5.04	96	90	82	72	63	51	40	29	17	5	0	0
MAY	3.90	86	70	59	51	43	33	24	16	2	0	0	0
JUN	4.52	93	84	75	66	53	42	30	11	0	0	0	0
JUL	5.22	95	89	83	74	65	56	43	27	3	0	0	0
AUG	5.72	96	93	88	82	75	64	52	38	10	1	0	0
SEP	4.59	88	74	68	61	56	49	43	34	20	0	0	0
OCT	4.16	87	78	72	66	62	55	45	32	19	0	0	0
NOV	2.85	83	71	59	50	43	36	28	19	7	0	0	0
DEC	2.32	79	61	54	46	39	30	22	11	0	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.27)	92	77	70	64	54	48	42	30	18	5	1	0
MAR	(3.42)	90	79	69	55	44	35	23	15	9	2	0	0
APR	(5.26)	96	90	79	73	65	56	46	35	19	2	0	0
MAY	(3.51)	90	71	56	45	36	26	18	11	5	0	0	0
JUN	(4.76)	94	85	77	68	57	46	32	23	3	0	0	0
JUL	(4.43)	91	80	71	59	49	40	32	23	8	0	0	0
AUG	(5.62)	95	88	82	78	71	63	52	40	17	0	0	0
SEP	(3.69)	87	73	64	54	45	36	30	24	15	2	0	0
OCT	(3.58)	92	81	72	64	58	49	40	32	14	0	0	0
NOV	(2.17)	81	63	51	43	37	31	20	13	3	0	0	0
DEC	(4.05)	97	96	92	92	87	81	72	54	22	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(2.72)	92	70	55	46	37	32	28	21	9	3	1	0
MAR	3.76	92	76	64	55	49	43	36	28	16	7	1	0
APR	(3.41)	90	74	60	46	36	28	20	13	8	1	0	0
MAY	3.60	90	72	56	44	33	27	20	15	7	2	0	0
JUN	4.74	94	86	76	68	57	46	34	21	1	0	0	0
JUL	(4.50)	93	82	73	66	55	43	35	25	1	0	0	0
AUG	(3.75)	89	71	63	53	44	37	29	20	6	0	0	0
SEP	(3.21)	90	74	62	53	46	36	29	21	12	3	1	0
OCT	(4.13)	96	89	83	76	70	60	50	37	20	0	0	0
NOV	2.03	67	55	48	43	37	32	25	17	7	0	0	0
DEC	(1.61)	66	51	45	35	28	25	19	12	4	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.91)	91	77	70	65	59	51	37	24	5	0	0	0
FEB	(1.66)	79	48	35	26	21	17	12	8	6	3	1	0
MAR	4.54	94	81	75	69	63	57	50	43	33	15	0	0
APR	(3.92)	92	81	66	55	45	35	26	20	9	1	0	0
MAY	4.59	93	83	73	65	56	48	37	25	13	2	0	0
JUN	4.87	94	87	77	69	60	49	35	21	5	0	0	0
JUL	4.92	94	86	79	71	62	51	38	22	4	0	0	0
AUG	(5.43)	96	89	85	80	71	63	53	39	15	2	0	0
SEP	5.40	96	91	85	80	73	66	57	45	26	2	1	0
OCT	(3.38)	81	69	61	55	46	41	32	23	9	0	0	0
NOV	(1.30)	55	44	37	30	25	19	12	4	1	0	0	0
DEC	(.80)	45	26	17	13	10	7	4	3	2	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.26)	72	58	49	41	36	31	24	17	4	0	0	0
FEB	(1.56)	61	33	24	21	18	15	12	9	6	2	0	0
MAR	3.05	86	66	55	47	40	33	25	18	10	4	0	0
APR	(4.41)	93	82	71	63	55	46	35	25	12	1	0	0
MAY	3.69	84	69	59	50	41	32	25	15	4	0	0	0
JUN	4.00	91	78	63	55	44	35	25	13	1	0	0	0
JUL	4.82	91	83	74	67	58	50	37	22	2	0	0	0
AUG	4.42	92	83	72	64	53	43	32	21	9	1	0	0
SEP	(3.78)	85	76	67	61	55	49	37	29	12	2	0	0
OCT	(3.23)	86	72	66	56	49	42	32	23	7	0	0	0
NOV	(1.64)	62	50	41	35	29	24	15	9	2	0	0	0
DEC	(.94)	32	26	22	21	16	10	7	2	0	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(.67)	28	19	17	13	10	5	3	2	1	0	0	0
FEB	1.98	63	44	38	32	27	20	15	9	5	0	0	0
MAR	(3.86)	92	77	66	58	51	46	36	28	12	0	0	0
APR	4.16	93	80	67	58	49	39	31	21	13	6	1	0
MAY	3.61	89	72	63	53	42	32	21	10	4	1	0	0
JUN	3.71	89	70	54	45	37	29	20	14	4	0	0	0
JUL	4.81	93	81	73	65	57	47	38	25	5	0	0	0
AUG	5.05	94	88	83	75	67	58	46	34	9	0	0	0
SEP	4.45	93	84	73	66	59	52	41	31	17	1	0	0
OCT	(2.37)	77	58	48	42	35	29	22	14	2	0	0	0
NOV	1.17	52	32	27	21	15	10	6	3	0	0	0	0
DEC	(1.06)	50	41	35	28	22	16	9	2	0	0	0	0

SOLAR RADIATION DATA for: LIBBY,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.14	60	42	32	24	18	13	7	4	2	0	0	0
FEB	(2.26)	69	45	36	34	29	26	22	15	9	0	0	0
MAR	(2.93)	84	67	54	43	34	27	19	11	3	1	0	0
APR	(4.51)	93	81	71	64	53	44	34	25	10	1	0	0
MAY	(4.20)	90	79	69	62	50	38	24	13	2	0	0	0
JUN	(4.33)	93	85	74	64	53	41	26	10	0	0	0	0
JUL	4.93	93	85	74	65	57	47	36	23	2	0	0	0
AUG	5.02	93	85	77	68	60	51	41	28	10	0	0	0
SEP	(4.70)	93	87	75	69	61	54	41	22	11	2	0	0
OCT	(2.54)	78	66	56	50	41	35	22	12	5	0	0	0
NOV	(1.26)	49	31	26	21	15	11	7	4	0	0	0	0
DEC	(.93)	42	29	25	21	12	3	0	0	0	0	0	0

LIVINGSTON NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: LIVINGSTON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.97)	95	76	66	62	54	49	39	30	22	16	6	0
MAR	4.64	93	83	75	68	59	54	46	38	30	20	4	2
APR	(4.22)	94	84	69	58	50	42	31	26	18	10	3	0
MAY	3.43	82	65	55	48	39	32	26	18	9	5	2	2
JUN	(5.23)	95	90	83	75	68	60	48	36	2	0	0	0
JUL	4.74	94	82	76	70	64	53	42	28	3	0	0	0
AUG	(5.11)	95	88	81	75	69	59	47	33	8	0	0	0
SEP	(5.11)	95	89	85	79	73	64	50	41	14	3	0	0
OCT	(4.71)	93	88	82	75	68	58	47	38	28	10	0	0
NOV	(4.00)	94	80	74	65	61	51	40	33	23	6	2	1
DEC	(2.21)	89	71	59	45	37	25	22	20	11	2	0	0

SOLAR RADIATION DATA for: LIVINGSTON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.11)	91	62	54	48	41	36	31	26	19	7	0	0
FEB	(2.88)	87	66	51	44	40	35	29	23	15	9	2	0
MAR	(4.35)	91	81	72	64	56	48	41	32	21	13	4	1
APR	(4.01)	93	78	66	57	51	41	29	20	11	3	0	0
MAY	(5.32)	95	90	81	76	69	58	44	30	6	1	0	0
JUN	(5.56)	96	92	86	80	73	63	49	30	1	0	0	0
JUL	(5.20)	95	88	83	76	68	57	43	24	0	0	0	0
AUG													
SEP													
OCT													
NOV	(3.41)	93	78	73	68	60	47	38	29	18	0	0	0
DEC	2.43	75	62	58	52	47	40	28	19	3	0	0	0

SOLAR RADIATION DATA for: LIVINGSTON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.85)	82	63	52	49	46	39	33	26	16	2	0	0
FEB	(2.98)	90	66	51	42	38	29	25	19	14	5	0	0
MAR	(4.02)	96	84	73	60	50	42	33	27	18	10	1	0
APR	(5.06)	95	88	82	74	66	54	45	34	21	3	0	0
MAY	4.24	92	80	72	63	54	45	32	20	5	0	0	0
JUN	(4.23)	90	82	73	63	52	41	28	15	1	0	0	0
JUL	4.96	95	89	82	76	69	60	45	27	2	0	0	0
AUG	(5.22)	96	91	86	82	73	63	52	36	10	3	0	0
SEP	(5.28)	97	93	87	83	71	61	55	45	28	8	1	0
OCT	(3.98)	86	71	67	62	55	49	43	34	21	2	0	0
NOV	2.92	86	71	61	55	46	38	28	18	10	3	0	0
DEC	(1.79)	71	50	41	32	25	18	13	8	1	0	0	0

SOLAR RADIATION DATA for: LIVINGSTON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.47)	93	76	72	70	66	57	47	36	22	6	4	0
MAR	5.15	94	84	77	71	64	57	49	42	32	19	1	0
APR	(4.93)	94	86	79	69	58	51	42	34	25	9	2	0
MAY													
JUN													
JUL	(4.92)	94	88	81	71	61	50	37	23	2	0	0	0
AUG	5.23	95	90	84	77	71	60	48	32	6	0	0	0
SEP	(4.77)	91	83	75	70	63	55	45	35	17	1	0	0
OCT	3.58	83	73	65	59	51	42	34	27	17	6	0	0
NOV	(3.84)	79	77	73	68	61	53	42	31	15	2	0	0
DEC	(1.95)	82	64	55	47	41	33	22	8	3	0	0	0

SOLAR RADIATION DATA for: LIVINGSTON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.62	75	52	41	34	28	18	13	9	2	0	0	0
FEB	(2.28)	86	54	45	37	32	24	16	11	9	5	0	0
MAR													
APR													
MAY													
JUN													
JUL	(4.91)	95	87	81	72	61	50	36	20	2	0	0	0
AUG	4.91	96	90	83	75	66	54	41	26	7	0	0	0
SEP	(3.84)	84	68	60	55	49	41	35	26	14	3	0	0
OCT	(3.17)	88	73	62	49	43	35	28	16	6	2	0	0
NOV													
DEC													

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.54)	92	74	67	63	53	47	37	26	16	5	1	0
FEB	4.26	91	82	75	69	63	54	46	36	25	4	0	0
MAR	4.49	91	83	74	64	57	48	39	29	19	4	0	0
APR	5.65	96	90	85	81	74	63	53	39	17	0	0	0
MAY	4.54	89	81	73	65	57	48	36	17	3	0	0	0
JUN	3.19	65	63	60	55	49	43	35	27	15	15	15	15
JUL	2.79	59	56	53	49	45	41	36	27	18	18	18	18
AUG	(4.54)	92	83	75	67	59	48	38	25	7	0	0	0
SEP	4.46	86	77	71	62	55	47	40	30	18	2	0	0
OCT	4.53	86	81	77	71	66	57	49	39	19	1	0	0
NOV	3.13	88	72	64	55	47	38	32	23	11	0	0	0
DEC	(2.29)	77	56	49	42	35	30	24	16	3	0	0	0

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.11	93	73	59	50	41	36	29	22	16	3	0	0
FEB	(3.87)	94	81	69	59	52	44	35	27	20	11	0	0
MAR	4.70	95	86	75	66	56	51	43	35	25	11	1	0
APR	4.05	83	73	61	53	47	41	35	27	19	3	0	0
MAY	3.71	82	66	56	46	41	35	27	17	2	0	0	0
JUN	4.64	94	86	76	66	56	45	33	11	0	0	0	0
JUL	(4.75)	93	87	78	68	58	50	37	17	1	0	0	0
AUG													
SEP	(4.80)	80	73	71	66	61	56	50	43	32	11	0	0
OCT	4.62	95	86	80	70	61	53	44	35	20	2	0	0
NOV	3.13	83	61	54	50	45	39	33	27	15	4	0	0
DEC	2.96	85	72	63	59	50	42	35	27	16	6	0	0

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	4.09	97	91	83	75	66	57	47	37	21	4	0	0
FEB	4.33	96	87	78	71	63	53	45	35	24	11	0	0
MAR	5.06	95	84	77	71	65	58	49	41	33	21	5	0
APR	4.18	89	75	65	55	48	39	31	23	15	5	0	0
MAY	4.48	93	84	72	61	52	43	32	19	5	1	0	0
JUN	5.01	94	88	79	69	60	49	34	20	2	0	0	0
JUL	(4.93)	94	88	79	67	58	50	37	16	0	0	0	0
AUG	(4.97)	97	92	86	75	64	50	35	25	7	0	0	0
SEP	5.51	96	91	86	81	73	65	54	42	23	1	0	0
OCT	(4.37)	94	84	78	69	60	52	45	33	17	0	0	0
NOV	2.96	84	72	62	53	43	36	29	20	8	0	0	0
DEC	3.19	89	79	71	64	52	43	34	23	1	0	0	0

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.19	83	73	67	60	54	47	35	24	12	0	0	0
FEB	(3.36)	83	66	60	54	48	42	37	26	18	5	0	0
MAR	4.17	93	83	72	62	53	40	31	21	14	4	0	0
APR	5.05	95	86	79	71	63	54	46	33	14	2	0	0
MAY	4.85	94	86	81	73	63	48	35	18	1	0	0	0
JUN	4.78	94	85	78	71	61	50	35	15	1	0	0	0
JUL	5.09	95	90	84	76	67	56	41	19	1	0	0	0
AUG	4.56	91	84	76	65	56	47	40	28	11	1	0	0
SEP	4.77	91	85	76	70	61	54	42	32	21	5	0	0
OCT	4.43	86	76	69	63	57	51	43	34	22	3	0	0
NOV	3.24	88	78	71	63	52	42	34	23	8	1	0	0
DEC	(2.00)	72	60	50	39	32	24	19	10	1	0	0	0

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.00)	94	86	81	73	64	58	48	36	21	0	0	0
FEB	3.91	93	81	70	64	54	47	39	30	22	8	0	0
MAR	(5.41)	96	89	83	77	69	60	53	45	34	18	1	0
APR	(5.05)	96	88	81	72	63	55	46	33	21	4	0	0
MAY	(3.83)	85	72	62	52	44	36	26	15	2	0	0	0
JUN	4.69	94	87	79	69	61	46	33	13	2	0	0	0
JUL	4.93	95	88	79	72	62	52	38	12	1	0	0	0
AUG	5.50	96	92	87	80	70	59	48	29	6	0	0	0
SEP	(5.56)	95	92	87	80	74	66	56	42	22	1	0	0
OCT	(4.51)	93	81	76	73	68	62	50	36	24	1	0	0
NOV	(3.05)	79	66	61	55	49	41	33	24	10	0	0	0
DEC	2.62	82	71	63	56	45	37	27	17	1	0	0	0

SOLAR RADIATION DATA for: MILES CITY,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.82	89	72	63	54	47	39	30	18	5	0	0	0
FEB	4.13	91	81	73	66	58	50	42	32	21	3	0	0
MAR	3.94	89	69	60	54	48	41	35	28	19	7	1	0
APR	4.58	93	82	72	63	54	46	37	30	19	4	0	0
MAY	(3.32)	83	60	48	40	32	24	18	13	4	1	0	0
JUN	4.53	90	83	76	67	54	40	29	9	0	0	0	0
JUL	4.80	93	83	76	68	59	48	35	17	1	0	0	0
AUG	(5.07)	94	87	81	75	68	59	44	26	1	0	0	0
SEP	4.35	87	78	71	61	56	47	39	30	16	1	0	0
OCT	3.78	84	75	68	61	53	44	34	27	14	4	0	0
NOV	3.12	88	76	67	59	50	41	32	22	8	2	0	0
DEC	2.05	81	56	46	37	28	22	15	5	0	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.82)	88	74	57	53	42	32	21	12	3	0	0	0
FEB	3.24	85	68	60	53	45	38	30	23	9	0	0	0
MAR	2.88	87	64	49	39	30	24	20	16	9	3	0	0
APR	5.14	96	87	80	73	65	57	44	33	20	5	0	0
MAY	3.59	89	72	57	49	39	29	21	13	6	1	0	0
JUN	(4.66)	94	84	77	66	54	44	30	18	2	0	0	0
JUL	(4.14)	91	79	68	60	51	40	27	13	2	0	0	0
AUG	4.66	92	81	72	66	60	53	42	32	11	2	0	0
SEP	(3.63)	90	73	64	52	46	40	34	29	16	3	0	0
OCT	(4.13)	93	81	73	66	58	49	39	30	17	3	0	0
NOV	(2.15)	79	65	56	48	39	33	24	14	6	4	2	2
DEC	(1.47)	68	43	30	29	20	17	13	9	4	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.46)	63	36	27	22	20	15	10	7	3	1	1	0
FEB	(2.39)	85	62	46	38	31	26	18	14	9	3	0	0
MAR	4.36	94	85	76	68	58	46	37	29	21	9	1	0
APR	4.03	95	83	71	59	48	39	27	20	12	4	0	0
MAY	(3.04)	87	64	49	36	29	21	14	10	5	1	0	0
JUN	4.50	91	83	75	67	58	49	33	14	2	0	0	0
JUL	4.70	93	84	76	68	58	50	39	25	4	0	0	0
AUG	4.59	92	83	74	66	58	46	35	23	4	0	0	0
SEP	3.61	78	68	60	55	47	40	30	23	16	5	3	2
OCT	(4.92)	97	91	85	76	69	62	50	39	23	9	1	0
NOV	(2.67)	76	64	56	51	45	39	30	19	10	1	1	0
DEC	1.93	74	55	47	40	33	27	19	9	2	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.70)	85	66	59	53	45	36	23	12	1	0	0	0
FEB	1.95	80	54	44	32	27	21	14	10	6	2	0	0
MAR	4.27	90	77	69	58	52	47	40	33	23	9	1	0
APR	3.74	91	77	66	48	40	32	25	18	10	1	0	0
MAY	(4.37)	92	80	69	59	51	41	32	20	6	1	0	0
JUN	4.82	90	83	76	68	59	48	39	26	2	0	0	0
JUL	5.05	94	89	83	75	68	55	44	27	2	0	0	0
AUG	4.96	92	85	80	73	67	58	48	34	12	1	0	0
SEP	5.94	98	94	90	83	76	69	57	45	30	3	0	0
OCT	(3.73)	87	73	62	57	49	44	37	29	19	3	0	0
NOV	2.42	74	62	55	48	41	33	25	9	1	0	0	0
DEC	(1.33)	56	43	35	30	25	19	12	5	1	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.79	81	66	58	53	47	38	29	19	6	0	0	0
FEB	2.10	78	57	45	38	29	23	13	8	2	1	0	0
MAR	2.92	92	72	57	43	35	26	17	10	5	2	0	0
APR	3.89	92	76	66	57	48	39	28	15	4	0	0	0
MAY	(3.79)	86	73	64	56	46	38	28	18	5	0	0	0
JUN	3.82	92	82	69	58	45	35	25	14	1	0	0	0
JUL	4.77	94	87	79	72	62	52	40	23	1	0	0	0
AUG	(5.02)	96	88	81	75	65	58	43	30	11	1	0	0
SEP	(3.89)	84	74	64	57	52	45	34	26	11	1	0	0
OCT	4.45	91	83	75	70	63	54	44	35	21	4	0	0
NOV	1.69	68	53	44	37	27	17	7	2	0	0	0	0
DEC	1.43	56	44	35	27	22	17	11	7	3	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.49	51	39	36	28	23	17	15	10	4	0	0	0
FEB	(3.48)	81	70	65	61	54	46	37	31	23	9	1	0
MAR	(5.33)	89	81	78	74	67	62	54	45	35	18	0	0
APR	(3.79)	84	67	58	53	47	37	30	22	12	4	1	0
MAY	(3.27)	90	74	57	41	32	21	16	7	1	0	0	0
JUN													
JUL													
AUG													
SEP	(4.37)	92	82	72	63	56	47	36	28	14	0	0	0
OCT	3.12	78	65	58	49	45	38	33	25	13	0	0	0
NOV	2.30	72	59	51	44	35	30	23	13	4	0	0	0
DEC	1.50	62	45	36	30	24	18	13	6	1	0	0	0

SOLAR RADIATION DATA for: MISSOULA,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.34	64	42	30	23	17	12	8	6	0	0	0	0
FEB	2.95	79	59	52	48	44	37	30	23	12	2	0	0
MAR	3.00	87	71	56	48	39	30	24	16	11	2	0	0
APR	3.88	91	78	65	56	48	41	31	19	9	0	0	0
MAY	4.04	86	75	65	57	49	39	29	17	3	0	0	0
JUN	4.42	92	85	77	69	61	51	37	11	0	0	0	0
JUL	4.58	93	86	77	70	60	47	30	11	2	0	0	0
AUG	(5.01)	95	89	82	75	66	57	45	26	9	1	0	0
SEP	(4.48)	93	81	72	65	59	52	46	33	20	3	0	0
OCT	3.03	81	66	58	52	43	37	31	22	11	1	0	0
NOV	2.33	79	65	53	44	39	30	22	12	3	1	0	0
DEC	(1.39)	61	44	36	26	22	14	9	3	0	0	0	0

PLENTYWOOD NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: PLENTYWOOD,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.52)	97	90	81	72	64	57	48	40	32	17	2	0
MAR	(4.86)	92	86	77	69	61	52	46	36	27	18	6	0
APR	(3.62)	79	65	55	49	44	38	33	24	13	4	0	0
MAY	(3.90)	85	74	64	55	44	34	25	14	4	1	0	0
JUN	(4.83)	92	82	75	68	58	50	40	24	5	0	0	0
JUL	4.59	91	84	75	69	60	50	38	19	4	1	1	1
AUG	(5.02)	95	89	82	77	69	60	47	32	14	1	0	0
SEP	(4.53)	90	83	79	73	66	58	48	36	18	1	0	0
OCT	(3.65)	83	75	71	66	58	52	44	34	24	14	7	6
NOV	2.52	78	60	51	46	40	33	27	18	4	1	1	1
DEC	2.45	87	69	55	46	41	32	25	13	2	0	0	0

SOLAR RADIATION DATA for: PLENTYWOOD,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.73)	95	87	82	73	63	57	51	31	8	0	0	0
FEB	3.52	94	80	62	53	44	40	36	29	19	7	0	0
MAR	4.20	91	76	65	59	53	46	38	32	23	15	3	0
APR	3.51	82	66	55	44	37	30	23	17	9	1	0	0
MAY	(3.66)	83	67	57	47	40	31	24	15	6	2	0	0
JUN	4.81	93	85	78	70	59	47	37	17	2	0	0	0
JUL	(5.03)	93	85	78	70	60	50	36	23	4	0	0	0
AUG	5.49	96	91	85	77	68	55	45	34	17	2	0	0
SEP	5.39	94	87	79	73	66	59	50	36	15	1	0	0
OCT	4.40	93	84	78	73	64	55	41	30	14	1	0	0
NOV	2.73	86	73	64	52	42	35	23	14	1	0	0	0
DEC	(2.96)	84	68	62	60	54	46	34	21	2	0	0	0

SOLAR RADIATION DATA for: PLENTYWOOD,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.31	89	77	72	66	55	47	37	27	7	0	0	0
FEB	(4.16)	94	83	74	68	60	52	44	34	24	9	0	0
MAR	(4.26)	94	81	70	62	53	43	37	26	15	5	1	0
APR	(5.29)	95	87	79	71	64	54	45	34	17	3	0	0
MAY	5.51	95	89	84	78	69	58	42	22	3	0	0	0
JUN	4.71	93	85	76	65	56	46	32	18	2	0	0	0
JUL	5.20	94	89	81	73	62	53	41	22	1	0	0	0
AUG	(4.84)	92	84	77	70	60	52	42	29	14	1	0	0
SEP	4.36	92	80	72	65	56	49	39	29	15	3	0	0
OCT	4.27	88	80	72	67	60	54	44	32	15	0	0	0
NOV	3.35	84	76	71	63	54	45	33	20	6	0	0	0
DEC	(2.20)	82	69	59	49	36	22	14	4	0	0	0	0

SOLAR RADIATION DATA for: PLENTYWOOD,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.94	80	61	56	51	46	38	35	27	12	1	0	0
FEB	4.12	94	86	80	70	65	56	46	31	21	10	0	0
MAR	5.50	94	89	83	77	70	63	55	45	35	17	1	0
APR	5.05	95	89	80	71	61	54	44	31	19	4	0	0
MAY	(3.76)	86	74	62	49	36	28	16	6	1	0	0	0
JUN	4.56	91	82	72	63	56	44	29	11	0	0	0	0
JUL	(5.17)	95	90	84	76	67	55	39	18	5	1	0	0
AUG	5.07	96	91	83	76	67	56	42	25	5	0	0	0
SEP	4.84	92	86	80	72	64	55	47	32	15	1	0	0
OCT	3.76	86	77	71	62	56	45	35	23	11	1	0	0
NOV	(2.96)	77	60	53	50	45	40	32	18	2	0	0	0
DEC	2.32	82	60	52	46	40	33	24	17	0	0	0	0

SOLAR RADIATION DATA for: PLENTYWOOD,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.67	93	71	59	50	42	33	24	13	3	0	0	0
FEB	(3.76)	95	81	71	60	53	44	37	27	14	0	0	0
MAR	(4.56)	93	83	72	62	54	46	40	32	24	10	1	0
APR	(4.61)	95	82	72	63	55	47	38	29	18	4	0	0
MAY													
JUN													
JUL													
AUG													
SEP	(4.85)	92	85	77	69	61	53	41	31	13	1	0	0
OCT	3.74	82	73	64	59	53	45	37	28	14	1	0	0
NOV	(2.99)	84	72	66	60	52	40	30	17	7	0	0	0
DEC	(1.67)	78	46	37	31	26	19	12	3	0	0	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.96)	65	51	35	29	27	16	12	6	2	0	0	0
FEB	(2.75)	74	62	53	46	38	32	26	20	11	4	0	0
MAR	3.01	86	70	58	48	37	30	25	18	13	7	0	0
APR	5.19	94	88	78	72	61	52	43	33	17	2	0	0
MAY	4.00	92	78	66	56	46	37	27	17	6	1	0	0
JUN	4.67	93	84	75	66	56	44	33	15	0	0	0	0
JUL	4.53	92	82	73	64	54	45	34	23	3	0	0	0
AUG	4.95	92	86	77	69	62	56	47	35	12	0	0	0
SEP	3.97	87	77	68	63	52	43	33	24	16	2	0	0
OCT	4.07	88	80	73	65	58	48	41	31	20	5	0	0
NOV	(2.30)	78	63	57	52	42	36	27	21	12	3	0	0
DEC	(1.59)	65	41	31	24	22	20	18	14	10	2	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.33	80	34	22	14	10	7	6	5	3	2	0	0
FEB	2.77	90	72	54	44	34	27	20	14	11	5	0	0
MAR	4.65	93	83	72	65	59	52	45	37	27	15	6	1
APR	4.16	93	80	67	59	49	39	31	20	10	1	0	0
MAY	3.51	87	72	57	48	36	27	21	14	4	1	0	0
JUN	4.81	91	85	78	71	64	54	42	25	3	1	0	0
JUL	(4.98)	94	89	82	74	65	56	45	28	1	0	0	0
AUG	4.65	92	84	75	66	58	50	42	28	8	1	0	0
SEP	(3.75)	87	70	59	52	46	40	32	27	16	3	0	0
OCT	4.74	94	88	82	75	68	57	52	40	23	4	0	0
NOV	2.22	69	52	43	39	34	28	23	16	9	1	1	0
DEC	1.79	70	48	38	34	30	26	19	10	6	1	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.32)	92	62	49	40	37	30	25	17	7	1	0	0
FEB	(2.25)	88	56	39	31	23	20	15	12	9	6	0	0
MAR	4.56	93	83	73	64	54	50	42	36	27	10	1	0
APR	3.89	90	78	66	58	47	40	31	20	11	2	0	0
MAY	(4.53)	91	79	68	59	50	44	33	22	6	0	0	0
JUN													
JUL													
AUG	(4.61)	93	83	77	68	60	53	46	39	15	0	0	0
SEP	5.64	97	94	89	84	74	67	57	44	26	1	0	0
OCT	3.68	81	73	66	60	52	45	36	27	15	2	0	0
NOV	1.50	47	36	29	24	22	17	15	9	5	0	0	0
DEC	(1.11)	52	37	30	22	16	12	8	5	2	0	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Foulkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.34	73	56	47	44	40	31	24	18	8	0	0	0
FEB	2.27	80	55	44	33	27	21	17	11	7	4	0	0
MAR	3.39	90	74	61	48	40	35	27	20	12	5	1	0
APR	4.52	90	79	69	62	54	46	38	28	14	1	0	0
MAY	4.08	87	77	64	57	49	41	32	23	5	0	0	0
JUN	4.39	91	80	70	59	53	42	31	17	0	0	0	0
JUL	4.99	94	86	79	70	63	51	40	26	1	0	0	0
AUG	(4.87)	94	85	78	72	64	56	44	32	12	0	0	0
SEP	4.20	89	78	71	64	57	45	37	28	16	1	0	0
OCT	(4.10)	91	78	72	64	58	49	40	33	19	0	0	0
NOV	(1.49)	61	47	38	33	26	18	11	6	1	0	0	0
DEC	(1.30)	48	40	34	27	22	20	16	9	3	0	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(.63)	26	17	15	12	8	5	3	2	2	0	0	0
FEB	2.37	71	51	43	37	32	27	21	17	11	3	0	0
MAR	4.38	89	77	69	62	56	49	41	32	23	10	0	0
APR	4.46	94	80	71	62	55	47	37	27	18	5	1	0
MAY	3.85	90	77	64	53	45	33	23	13	3	0	0	0
JUN	3.79	87	72	60	50	41	32	19	9	1	0	0	0
JUL	5.14	95	91	83	76	66	55	41	23	1	0	0	0
AUG	5.48	95	89	83	77	69	61	51	30	4	0	0	0
SEP	5.06	92	88	82	76	69	61	50	38	23	3	0	0
OCT	2.99	83	67	53	45	40	33	29	21	13	1	0	0
NOV	(2.47)	73	68	61	49	41	34	26	16	6	0	0	0
DEC	1.62	59	46	40	33	27	22	18	13	6	0	0	0

SOLAR RADIATION DATA for: POLSON,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.17	64	31	17	13	11	8	6	4	3	1	0	0
FEB	(2.72)	78	60	46	39	35	32	27	23	17	5	0	0
MAR	3.17	85	73	62	51	47	38	30	21	13	4	1	0
APR	4.42	93	83	72	64	55	46	38	27	14	2	0	0
MAY	4.32	87	76	66	59	49	42	32	21	5	0	0	0
JUN	(4.59)	93	82	74	66	57	46	30	13	0	0	0	0
JUL	(4.55)	93	83	73	65	54	43	33	16	1	0	0	0
AUG	4.76	94	87	77	70	61	50	40	24	3	0	0	0
SEP	4.55	87	80	74	66	58	51	43	29	15	1	0	0
OCT	2.75	80	65	55	50	42	34	25	15	7	1	0	0
NOV	1.80	63	42	37	30	24	19	15	9	4	0	0	0
DEC	(1.06)	56	39	26	20	13	7	2	0	0	0	0	0

RED LODGE NOT INSTRUMENTED IN 1977

REDLOGE??1978 SOLAR RADIATION DATA for: REDLODGE,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.60)	88	69	62	51	47	42	38	29	23	18	4	0
MAR	4.76	89	81	74	65	59	52	44	34	27	14	3	0
APR	(3.37)	83	71	61	49	39	34	27	20	12	3	0	0
MAY	3.59	85	67	57	48	41	35	24	15	7	1	0	0
JUN	(3.92)	91	79	64	51	43	35	28	17	2	0	0	0
JUL	4.29	88	78	70	61	54	45	35	23	6	0	0	0
AUG	(4.56)	90	79	72	64	60	52	44	31	12	1	1	1
SEP	(4.70)	91	82	75	67	56	48	39	31	21	6	2	0
OCT	(5.22)	97	93	89	83	75	66	57	44	25	3	0	0
NOV	3.42	90	72	64	57	50	42	33	24	16	3	0	0
DEC	3.18	93	82	75	65	58	50	40	29	11	0	0	0

SOLAR RADIATION DATA for: REDLODGE,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.79	95	83	69	63	57	53	44	35	24	6	0	0
FEB	4.05	95	85	76	68	58	50	42	31	20	6	0	0
MAR	(4.44)	92	81	73	65	58	51	43	31	19	8	1	0
APR	4.35	93	81	70	63	54	46	34	23	10	1	0	0
MAY	4.28	89	77	67	58	49	40	30	19	3	0	0	0
JUN	4.68	93	85	77	66	57	46	34	17	1	0	0	0
JUL	4.63	92	84	76	68	59	49	36	21	2	0	0	0
AUG	(4.28)	89	79	69	62	56	46	36	24	9	1	0	0
SEP	5.83	97	93	88	84	77	70	60	50	36	11	1	0
OCT	4.37	88	81	75	69	60	52	44	35	24	8	2	0
NOV	4.04	93	81	74	68	62	53	44	36	25	9	1	0
DEC	3.38	89	80	75	69	60	54	43	33	13	0	0	0

SOLAR RADIATION DATA for: REDLODGE,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.34	91	75	63	60	52	44	34	25	17	4	0	0
FEB	3.73	94	83	71	60	53	40	34	26	19	9	1	0
MAR	4.16	94	79	67	58	50	42	32	26	18	8	1	0
APR	(5.30)	97	91	82	75	67	55	47	36	20	3	1	0
MAY	4.00	91	79	69	56	44	35	23	14	2	0	0	0
JUN	4.57	93	83	75	67	58	48	34	17	0	0	0	0
JUL	4.42	94	87	79	70	61	48	33	19	2	0	0	0
AUG	4.24	91	80	69	61	53	43	36	24	8	0	0	0
SEP	4.48	93	79	70	63	57	51	43	33	22	5	1	0
OCT	4.84	93	83	74	67	61	54	47	39	28	10	0	0
NOV	3.32	85	69	61	54	47	41	34	27	19	9	1	0
DEC	2.56	82	67	59	53	46	36	25	19	9	0	0	0

SOLAR RADIATION DATA for: REDLODGE,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	4.26	93	85	78	74	68	63	54	43	28	9	1	0
FEB	(4.67)	97	91	80	72	65	57	48	38	30	18	5	0
MAR	5.34	95	87	79	72	66	58	51	42	33	21	2	0
APR	4.82	95	85	76	67	58	48	40	30	20	6	1	0
MAY	3.49	87	72	60	46	35	26	18	9	3	0	0	0
JUN	4.34	92	81	71	60	51	41	29	13	1	0	0	0
JUL	4.53	90	82	76	67	58	48	36	19	2	0	0	0
AUG	(5.02)	95	89	83	73	67	60	47	30	6	0	0	0
SEP	5.14	94	87	81	76	68	62	51	39	19	2	0	0
OCT	3.84	88	74	61	55	50	44	35	27	17	7	1	0
NOV	4.14	92	87	82	77	66	59	50	38	23	5	0	0
DEC	3.14	93	82	73	65	58	49	40	28	15	3	0	0

SOLAR RADIATION DATA for: REDLODGE,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM)											
		>.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	2.83	90	70	60	53	47	40	29	21	11	2	0	0
FEB	4.28	92	85	75	66	60	52	43	35	23	8	0	0
MAR	4.08	92	77	68	59	50	44	34	26	16	8	2	0
APR	4.78	93	84	75	67	57	49	40	30	14	5	1	0
MAY	(3.78)	89	74	62	49	40	31	22	12	1	0	0	0
JUN	3.67	87	74	60	49	40	30	17	6	0	0	0	0
JUL	4.34	92	83	72	64	53	41	28	16	2	0	0	0
AUG	(4.68)	94	86	79	70	62	53	40	25	10	1	0	0
SEP	4.65	92	78	70	64	55	48	40	32	20	4	0	0
OCT	4.65	96	86	80	74	66	59	50	39	25	10	1	0
NOV	3.57	91	79	73	67	60	50	39	27	17	3	0	0
DEC	2.59	88	70	61	49	42	32	24	15	2	0	0	0

SIDNEY NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: SIDNEY,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(4.56)	97	92	81	71	62	50	44	37	30	21	2	0
MAR	(4.74)	97	89	79	67	58	50	43	36	27	14	4	1
APR	(3.44)	82	61	53	46	41	36	32	25	16	5	1	0
MAY	(3.66)	86	71	62	55	49	43	36	24	3	0	0	0
JUN	(4.04)	91	76	67	59	54	48	39	23	6	1	0	0
JUL													
AUG													
SEP													
OCT													
NOV	(2.84)	79	57	49	47	43	40	32	23	14	0	0	0
DEC	(2.09)	78	60	48	40	33	24	15	6	0	0	0	0

SOLAR RADIATION DATA for: SIDNEY,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.52	96	85	74	69	59	49	37	27	11	0	0	0
FEB	(3.51)	93	77	58	50	43	36	31	26	21	7	1	0
MAR	(4.66)	94	83	74	64	55	50	46	37	27	13	1	0
APR	(4.07)	87	74	65	60	47	38	29	20	12	2	0	0
MAY	(3.95)	89	75	61	55	46	37	27	16	1	0	0	0
JUN	(4.45)	94	83	72	63	51	38	26	13	1	0	0	0
JUL	4.59	93	83	74	66	57	45	36	21	1	0	0	0
AUG	(4.87)	95	85	78	71	61	51	41	30	7	0	0	0
SEP	5.65	96	91	86	81	75	68	57	45	30	1	0	0
OCT	(4.21)	93	84	76	68	59	50	42	32	18	2	0	0
NOV	2.83	87	75	62	51	46	37	27	16	1	0	0	0
DEC	(2.83)	82	75	68	63	52	40	30	18	0	0	0	0

SOLAR RADIATION DATA for: SIDNEY,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	3.22	87	76	69	59	52	42	32	20	8	0	0	0
FEB	3.53	83	71	62	55	48	42	32	27	19	3	1	0
MAR	(4.54)	96	88	76	68	60	53	41	31	20	8	1	0
APR													
MAY													
JUN	(4.57)	93	84	77	68	54	44	29	14	0	0	0	0
JUL	4.45	92	82	73	65	54	44	31	10	1	0	0	0
AUG	(4.09)	86	76	68	60	50	39	32	21	6	0	0	0
SEP	4.21	89	78	68	62	56	48	37	27	13	1	0	0
OCT	(4.61)	89	81	76	71	63	54	46	36	22	0	0	0
NOV	3.24	90	78	70	62	53	44	36	23	9	1	0	0
DEC	(2.27)	86	67	61	55	40	32	23	13	2	0	0	0

SOLAR RADIATION DATA for: SIDNEY,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(3.86)	93	83	74	68	60	52	43	31	19	5	0	0
MAR	(5.53)	91	87	84	79	73	66	56	46	33	8	0	0
APR	4.43	94	83	71	60	54	48	38	27	11	2	0	0
MAY	(3.73)	82	65	59	53	45	36	25	10	0	0	0	0
JUN													
JUL													
AUG													
SEP	(4.46)	82	80	73	70	61	56	46	32	15	2	0	0
OCT	3.69	87	76	67	59	50	41	34	25	9	0	0	0
NOV	(4.63)	96	88	84	78	70	62	52	40	12	0	0	0
DEC													

SOLAR RADIATION DATA for: SIDNEY,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.81)	75	56	45	40	30	22	16	8	3	0	0	0
FEB	2.57	87	70	61	53	44	36	29	19	7	0	0	0
MAR	(3.39)	89	70	60	51	42	36	30	22	12	4	0	0
APR	(3.91)	91	79	63	49	42	35	28	20	11	6	2	1
MAY													
JUN													
JUL													
AUG													
SEP													
OCT													
NOV	2.92	89	79	69	62	50	39	29	15	4	0	0	0
DEC	1.80	71	55	44	36	26	18	11	4	0	0	0	0

THOMPSON FALLS NOT INSTRUMENTED IN 1977

SOLAR RADIATION DATA for: THOMPSON FALLS,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN													
FEB	(2.21)	74	53	41	34	29	23	18	16	10	2	0	0
MAR	(3.41)	88	69	57	48	43	37	32	27	20	10	3	0
APR	(3.56)	92	77	63	52	44	35	27	17	8	1	0	0
MAY	3.22	90	66	50	41	35	30	24	16	9	4	0	1
JUN	(4.62)	91	82	74	66	56	47	37	26	4	0	0	0
JUL	(4.42)	91	81	73	63	54	45	36	20	2	0	0	0
AUG	(3.42)	75	64	56	48	40	34	27	21	12	2	0	0
SEP													
OCT	(4.47)	94	86	81	76	68	57	47	32	14	1	0	0
NOV	2.02	65	49	39	35	31	25	18	11	4	0	0	0
DEC	(1.39)	53	35	29	25	19	15	13	7	3	1	0	0

SOLAR RADIATION DATA for: THOMPSON FALLS,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.87)	82	71	60	55	48	38	31	22	7	1	0	0
FEB	(1.89)	79	53	36	29	17	14	10	7	4	1	0	0
MAR	4.42	93	80	69	62	58	50	42	33	22	10	1	0
APR	3.90	91	77	65	59	50	40	30	19	10	3	0	0
MAY	(4.12)	91	79	68	57	46	37	26	13	1	0	0	0
JUN	(4.69)	93	86	75	66	57	48	38	25	5	0	0	0
JUL													
AUG													
SEP													
OCT	(3.11)	86	71	59	50	44	36	32	23	10	3	0	0
NOV													
DEC													

SOLAR RADIATION DATA for: THOMPSON FALLS,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.03)	95	85	79	71	64	52	41	30	15	0	0	0
FEB	2.13	77	48	38	30	25	18	14	10	6	2	0	0
MAR	(2.68)	86	62	46	37	30	24	17	9	6	2	0	0
APR	(4.58)	94	83	73	63	52	43	35	27	14	0	0	0
MAY													
JUN	(3.97)	89	71	62	50	41	32	27	19	6	0	0	0
JUL	4.57	93	85	76	68	58	47	35	18	1	0	0	0
AUG	(4.63)	93	84	75	66	58	48	36	25	11	1	0	0
SEP	4.02	91	79	70	64	53	43	35	25	12	1	0	0
OCT	3.86	87	75	68	64	59	54	44	31	15	0	0	0
NOV	1.49	64	47	35	28	23	17	13	7	1	0	0	0
DEC	(.67)	31	20	14	12	6	5	3	1	0	0	0	0

SOLAR RADIATION DATA for: THOMPSON FALLS,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	1.49	62	46	38	31	24	21	14	5	1	0	0	0
FEB	(2.64)	79	61	53	43	37	31	26	18	9	4	1	0
MAR	4.15	89	74	66	58	52	45	40	31	20	8	0	0
APR	(4.02)	92	77	66	55	45	39	31	23	12	2	1	0
MAY	3.21	87	69	54	40	29	20	12	6	0	0	0	0
JUN	3.62	87	67	56	45	36	27	20	15	3	0	0	0
JUL	5.03	94	89	82	75	67	55	45	27	3	0	0	0
AUG	5.24	95	89	84	79	71	63	53	35	10	1	0	0
SEP	(5.18)	96	91	83	75	68	60	50	39	20	1	0	0
OCT													
NOV													
DEC													

SOLAR RADIATION DATA for: THOMPSON FALLS,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.07)	49	33	25	21	14	8	3	1	0	0	0	0
FEB													
MAR													
APR	(4.39)	95	87	77	65	53	43	33	20	5	1	0	0
MAY	3.80	90	75	60	49	41	34	24	14	2	0	0	0
JUN													
JUL													
AUG													
SEP													
OCT													
NOV													
DEC													

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1977

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.98)	98	95	86	80	76	67	62	53	40	21	3	0
FEB	5.14	97	89	81	76	69	62	53	43	34	22	4	0
MAR	3.92	95	84	70	56	43	33	25	20	13	7	1	0
APR	(5.17)	91	85	80	73	66	59	48	36	20	3	0	0
MAY	(3.54)	91	78	65	52	40	28	17	9	3	0	0	0
JUN	4.60	94	87	78	70	61	48	37	14	2	0	0	0
JUL	(4.76)	95	87	77	69	58	46	34	21	1	0	0	0
AUG	(3.27)	93	83	55	42	32	22	15	13	6	2	0	0
SEP	(4.77)	92	84	77	67	60	53	46	37	24	5	1	0
OCT	(5.34)	97	93	86	79	70	63	53	39	27	9	0	0
NOV	(2.55)	80	65	50	42	38	31	23	16	10	6	1	0
DEC	(2.09)	72	55	44	41	34	28	24	20	15	7	1	0

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1978

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.37)	76	39	22	17	14	13	11	8	6	1	1	0
FEB	(3.30)	91	73	62	50	44	38	32	25	19	13	5	0
MAR	4.81	95	85	75	69	63	55	46	38	26	13	3	0
APR	4.20	95	86	73	60	47	38	29	22	15	4	1	0
MAY	3.76	91	79	64	52	41	33	21	13	3	1	0	0
JUN	4.64	93	86	77	68	59	49	35	12	2	0	0	0
JUL	(4.60)	94	86	78	67	57	48	35	17	1	0	0	0
AUG													
SEP	(5.78)	96	88	83	78	73	67	59	48	36	11	1	0
OCT	5.78	97	94	90	85	78	71	61	51	36	12	0	0
NOV	2.70	80	61	51	45	38	33	28	23	16	4	0	0
DEC	2.88	77	64	55	50	43	38	32	23	12	3	0	0

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1979

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(3.67)	87	72	62	57	52	48	44	36	29	17	2	0
FEB	2.86	90	70	51	43	34	27	22	18	14	10	5	0
MAR	5.10	94	84	74	67	60	53	47	39	31	20	7	2
APR	(5.32)	96	91	85	75	65	56	45	31	17	2	0	0
MAY	(4.91)	94	87	77	66	56	46	37	23	7	1	0	0
JUN	(4.55)	93	85	77	66	56	45	30	12	0	0	0	0
JUL	5.07	95	89	83	75	66	56	44	27	1	0	0	0
AUG	4.49	91	83	75	69	61	52	42	31	12	1	0	0
SEP	6.09	98	95	91	87	80	73	62	50	31	3	0	0
OCT	(4.33)	90	80	73	66	60	52	44	35	23	5	0	0
NOV	(2.33)	66	56	48	42	36	30	27	17	13	9	7	3
DEC	(3.07)	79	62	58	55	51	49	45	32	21	8	0	0

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1980

Montana Department of Natural Resources and Conservation
compiled by: Fowlkes Engineering, Bozeman, Mt.

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(2.36)	73	52	45	42	37	30	25	18	12	3	0	0
FEB	(3.19)	85	64	55	48	41	34	29	24	18	12	4	0
MAR	(3.87)	93	79	63	50	44	37	28	21	16	9	3	0
APR	5.17	96	90	83	76	67	57	43	33	21	5	1	0
MAY	(3.74)	92	79	66	56	45	35	25	13	6	0	0	0
JUN	(4.34)	93	81	71	62	51	42	33	19	2	0	0	0
JUL	4.84	95	88	82	74	66	55	43	26	4	0	0	0
AUG	(5.09)	92	85	79	74	67	58	48	35	15	1	0	0
SEP	(4.79)	95	88	82	74	67	55	49	37	25	8	1	0
OCT	4.56	92	79	72	65	60	54	43	35	24	7	0	0
NOV	2.86	78	60	52	48	43	38	30	21	12	4	0	0
DEC	(2.07)	72	52	45	37	31	24	17	9	3	0	0	0

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1981

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(4.25)	96	88	82	73	66	60	51	43	33	10	0	0
FEB	(3.75)	93	80	70	62	52	44	36	29	24	14	3	0
MAR	(5.18)	96	89	80	71	62	55	46	38	30	19	5	1
APR	(4.31)	94	82	72	60	51	39	29	19	10	1	0	0
MAY	(3.74)	91	76	61	51	41	31	22	12	2	0	0	0
JUN	4.33	91	80	71	62	52	39	28	14	1	0	0	0
JUL	(5.19)	94	90	84	78	71	60	48	31	3	0	0	0
AUG	(4.93)	95	89	82	75	68	59	46	30	11	0	0	0
SEP	5.26	93	87	81	74	67	58	50	40	26	3	1	0
OCT	(4.06)	93	83	73	68	61	55	45	38	26	10	0	0
NOV	(2.33)	63	52	47	42	37	26	22	16	8	0	0	0
DEC	(1.90)	75	55	43	33	28	23	18	13	8	2	0	0

SOLAR RADIATION DATA for: WEST YELLOWSTONE,MONTANA 1982

MONTH	DAILY AVERAGE KWH/SM/DAY	PER CENT TOTAL ENERGY ABOVE THRESHOLD (KW/SM) >.1	>.2	>.3	>.4	>.5	>.6	>.7	>.8	>.9	>1.0	>1.1	>1.2
JAN	(1.68)	53	45	42	35	29	27	13	10	4	0	0	0
FEB													
MAR													
APR													
MAY													
JUN	(3.43)	93	82	66.	54	36	18	1	0	0	0	0	0
JUL	(3.68)	91	80	71	60	47	37	25	10	4	2	0	0
AUG	(2.47)	84	61	51	43	34	28	24	20	13	6	0	0
SEP													
OCT													
NOV													
DEC													

SECTION 5

MANUAL STATIONS, 1977-1982

RADIATION (kWh/M2) x 317 = RADIATION (BTU/ft^2)

MANUAL SOLAR MEASUREMENT STATION

1977-78 Average Radiation, kWh/m^2-day

STATION	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Baker													2.70
Big Timber			2.08	.63	.82	1.44	1.99	1.74	2.74				
Billings													3.04
Boulder													2.82
Broadus	5.31	5.10	2.82	3.94	3.13	4.81	5.04			2.73	5.03	3.01	2.62
Chester		3.89	3.39	1.95	2.47	3.38	3.86	3.28		5.19	5.06	3.15	2.29
Chinook	4.24	5.83	4.65	2.95	2.28	4.01	5.16	4.09	4.87				
Circle	3.87	5.17	3.30	2.17	2.66	3.77	3.28	5.18	2.90				
Columbus		4.82	3.20	2.33	2.61	2.95	4.76						
Conrad													3.14
Culbertson													2.00
Deer Lodge	4.10	5.15	2.37	1.27		3.08	4.93	4.04	3.35	4.46	4.19	3.43	
Ekalaka	5.05	6.15	3.47	2.93	3.29	4.75	4.65	5.08	4.53	5.67	4.60	3.38	2.07
Forsyth													2.62
Hardin			3.92	2.49	2.93	4.36	6.13	4.49	3.52	6.64	4.75	4.15	
Harlem													2.35
Hobson	4.96	4.38	2.68	1.45	2.59	3.59		5.24	3.78	4.42	4.23	3.60	2.11
Malta		5.61	3.55	2.46	1.74	3.49	3.60	4.28	4.11		3.98	2.44	2.22
Missoula													1.82
Roundup	4.11	5.39	3.33	1.53	1.94	2.87	4.86	5.20	4.55	5.18	4.77	3.17	2.26
Superior	3.04	4.13						3.19			4.24	1.77	
Townsend	6.67	5.44	2.93	1.45	2.54	4.58	5.26	4.76	4.71	4.48	4.78	3.62	1.97
Wh.Sulphur Spgs.		4.02	2.71	1.20	2.25	4.23	4.34	4.85			5.25	3.13	2.12
Winnett	5.87	5.64	4.00	2.44	2.24	3.22	4.82	5.90	5.01				
Wolf Point	5.05	5.79	4.02	2.89	3.63	4.36	5.43	5.54	4.42	4.87	2.83	1.78	

MANUAL SOLAR MEASUREMENT STATION

1979 Average Radiation, kWh/m^2-day

STATION	JAN	FEB	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Baker	4.48	4.53	5.29	3.97	4.55			2.74	2.90
Billings	3.23	2.39	3.21	2.05	3.52				2.77
Boulder	3.30	2.55	4.67	3.16	4.03		2.98	4.10	2.07
Broadus	4.16					5.58		4.52	3.23
Chester	3.50	3.13	4.94	3.87	5.15	4.99	4.11	3.86	1.81
Circle			4.03						
Conrad	2.58		4.57	3.36	4.96	5.33	4.01	3.86	1.80
Deer Lodge	1.90		3.43			4.26	2.90	2.07	1.13
Ekalaka	4.01	4.08	5.13	3.95	5.33	6.68	5.57	3.49	2.73
Eureka			4.11	2.72	4.56	3.51	2.56		
Forsyth	3.62	3.29	3.95	3.76	4.55				
Great Falls	4.35	3.35	4.95	4.03	4.49		3.26	3.39	2.19
Harlem	3.02					5.07	3.48		
Hobson	2.92	2.98	4.74	3.97	4.36				1.61
Malta	2.88	3.46	4.55	3.68	4.44	4.38	4.04	2.87	1.29
Missoula	2.50	1.92	4.39	4.02	6.21			3.8	1.03
Roundup	3.62	3.94	3.38	4.19			4.02	2.94	3.15
Scobey	3.33	3.22							
Superior			3.19						
Townsend	3.20	2.83	4.90	3.88	5.65	5.44	3.42	4.53	2.13
Whitefish	2.42	2.55	3.68	3.83	3.96	4.63	4.32	1.70	.93
Wh.Sulphur Spgs.	3.97	2.82	4.92	3.88		5.51	4.00	3.35	1.39
Wolf Point	2.03	2.43							2.71

MANUAL SOLAR MEASUREMENT STATIONS

1980 Average Radiation, kWh/m^2-day

STATION	JAN	FEB	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Baker	3.63	3.16	4.37	5.21	5.17	5.02	5.11	3.83	2.03
Billings	2.49	2.66	5.23	5.41	5.65	4.44	5.53	2.94	1.97
Boulder	2.65	2.96	3.38	4.96	4.76	4.41	3.64	2.86	2.03
Broadus						4.88	4.39	4.29	2.67
Chester	3.42	3.07	4.05	3.32					
Conrad	2.99								
Deer Lodge	2.34								
Ekalaka	4.02	3.62				4.98	4.35	3.96	2.39
Eureka	2.01	1.25	2.25	3.82	3.48				
Great Falls	3.39								
Hobson	2.34	2.35	3.23	5.52	6.24	3.4		2.69	2.96
Malta	2.39	2.58	3.9	4.41	4.35	3.09	2.79	1.88	1.76
Missoula	3.89	2.15	3.22	3.25	6.13	4.37	4.47	2.41	1.83
Roundup	3.32	3.89	3.79	5.35	5.83	5.84	5.13	2.54	1.55
Townsend	2.94	1.96	3.44	3.95	6.48	5.98	4.22	1.89	1.37
Whitefish	2.13	1.5	3.79	4.24	4.47			.97	1.55
Wh.Sulphur Spgs.	3.14	3.25	5.33	5.92	6.2	5.01	5.86	2.46	1.97
Wolf Point	3.26	3.17	4.83	4.68					

MANUAL SOLAR MEASUREMENT STATIONS

1981 Average Radiation, kWh/m^2-day

STATION	JAN	FEB	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Baker	3.57	3.92	5.33	5.06	4.09	5.19	3.75	3.41	2.92
Billings	4.18	3.47	4.79	4.8	4.23	6.01	3.17	3.21	4.05
Boulder	2.77	4.47	3.76	4.78	4.16	4.97	3.16	2.62	1.83
Broadus	2.65	4.89	5.26	5.53	5.09				
Chester									5.25
Ekalaka	3.61	3.73	5.96	4.98	7.36	6.81	5.08	4.24	4.28
Hobson	3.59	3.11		5.5	2.68	4.13	2.32	1.81	2.25
Malta	1.88	2.9	3.27	3.21		3.29	2.58	1.84	1.61
Missoula	1.70	4.46	5.71	3.63		4.99	2.45	2.62	2.37
Roundup	4.24	4.35	5.38	4.34					
Townsend	2.21	2.64	3.59	2.91	2.77	5.11	3.45	2.31	1.98
Whitefish			4.49	4.77	1.76				
Wh.Sulphur Spgs.	4.12	2.73			3.76	5.44	4.22	2.86	3.35
Wolf Point						3.67	3.88	3.54	

MANUAL SOLAR MEASUREMENT STATIONS

1982 Average Radiation, kWh/m^2-day

STATION	JAN	FEB	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Baker	3.03	4.28	3.58	4.01	2.95	4.25	2.8	3.03	2.15
Billings	2.66	4.22	3.34	4.97	5.09	3.96	2.99	2.3	1.88
Boulder	1.30	4.29	2.84	4.53	4.22	2.91	3.79	2.12	.92
Ekalaka	3.31	6.26	4.19	5.97	5.15	5.93	4.00	3.83	3.66
Hobson	2.22	3.26	3.21	3.84	(5.14)	(4.09)	(3.55)	2.15	
Malta	1.77	2.97	2.28	3.58	2.41	2.35	2.14		.88
Missoula	3.08	2.3	2.77	5.13	4.37	4.29	3.35	3.55	1.37
Townsend	1.59	3.11	2.45	4.14	4.80			2.45	1.99
Wh.Sulphur Spgs.	2.22	4.5	3.66	7.51	6.04	5.04	4.39	2.74	2.79
Wolf Point	2.33	4.32	(4.9)						

SECTION 6

CLOUDY DAY OCCURRENCE STATISTICS

alphabetical by station

These data show the number of exclusive Occurrences of periods having 1 CLOUDY DAY, 2 (successive) CLOUDY DAYS, 3 (successive) CLOUDY DAYS, etc.. Each cloudy day is only counted once.

The cloudy day occurrence statistics can be used to make design decisions about energy storage requirements and back-up energy system requirements.

Note: The total number of data-days during the period are shown in parentheses above each table of occurrence statistics.

ANACONDA NOT INSTRUMENTED IN 1977

ANACONDA, 1978

YEAR ROUND(221)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	11	7	4	0	0	0	0	0

HEATING SEASON(129)							
1	2	3	4	5	6	7	>7
8	7	2	0	0	0	0	0

ANACONDA, 1979

YEAR ROUND(313)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	5	1	0	1	0	0	0

HEATING SEASON(200)							
1	2	3	4	5	6	7	>7
18	5	1	0	1	0	0	0

ANACONDA, 1980

YEAR ROUND(312)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	20	5	5	0	0	0	0	0

HEATING SEASON(221)							
1	2	3	4	5	6	7	>7
18	5	5	0	0	0	0	0

ANACONDA, 1981

YEAR ROUND(280)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	4	0	1	0	0	0	0

HEATING SEASON(171)							
1	2	3	4	5	6	7	>7
19	3	0	1	0	0	0	0

ANACONDA, 1982

YEAR ROUND(248)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	18	12	1	0	0	1	0	0

HEATING SEASON(189)							
1	2	3	4	5	6	7	>7
18	11	0	0	0	1	0	0

BILLINGS, 1977

YEAR ROUND(292)									HEATING SEASON(166)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	15	5	0	0	0	0	0	0	12	5	0	0	0	0	0	0

BILLINGS, 1978

YEAR ROUND(337)									HEATING SEASON(218)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	16	9	2	1	1	0	0	0	11	9	2	1	1	0	0	0

BILLINGS, 1979

YEAR ROUND(333)									HEATING SEASON(220)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	25	4	1	0	0	0	0	0	24	3	1	0	0	0	0	0

BILLINGS, 1980

YEAR ROUND(351)									HEATING SEASON(217)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	22	8	2	0	1	0	0	0	20	8	2	0	1	0	0	0

BILLINGS, 1981

YEAR ROUND(307)									HEATING SEASON(173)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	21	8	0	0	0	0	0	0	17	7	0	0	0	0	0	0

BILLINGS, 1982

YEAR ROUND(290)									HEATING SEASON(178)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	25	7	2	0	0	0	0	0	22	6	1	0	0	0	0	0

BOZEMAN, 1977

YEAR ROUND(344)									HEATING SEASON(217)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	22	12	1	2	0	0	0	1	18	11	1	1	0	0	0	1

BOZEMAN, 1978

YEAR ROUND(353)									HEATING SEASON(223)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	11	9	5	2	0	0	0	0	7	9	4	2	0	0	0	0

BOZEMAN, 1979

YEAR ROUND(358)									HEATING SEASON(226)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	23	5	3	0	0	0	0	0	20	5	3	0	0	0	0	0

BOZEMAN, 1980

YEAR ROUND(339)									HEATING SEASON(210)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	29	7	2	2	0	0	0	0	19	7	2	2	0	0	0	0

BOZEMAN, 1981

YEAR ROUND(351)									HEATING SEASON(217)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	25	9	2	0	0	0	0	0	23	8	2	0	0	0	0	0

BOZEMAN, 1982

YEAR ROUND(348)									HEATING SEASON(214)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	29	6	3	2	0	0	0	0	25	6	3	1	0	0	0	0

BROWNING, 1977

YEAR ROUND(229)									HEATING SEASON(132)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	11	7	2	2	0	0	0	0	8	5	1	2	0	0	0	0

BROWNING, 1978

YEAR ROUND(287)									HEATING SEASON(154)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	20	4	2	0	0	0	0	0	12	3	2	0	0	0	0	0

BROWNING, 1979

YEAR ROUND(185)									HEATING SEASON(104)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	6	3	1	0	0	0	0	0	6	2	1	0	0	0	0	0

BROWNING, 1980

YEAR ROUND(136)									HEATING SEASON(103)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	9	2	1	0	0	0	0	0	8	2	0	0	0	0	0	0

BROWNING, 1981

YEAR ROUND(166)									HEATING SEASON(107)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	9	2	0	0	0	0	0	0	7	2	0	0	0	0	0	0

BROWNING, 1982

YEAR ROUND(331)									HEATING SEASON(225)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	27	8	2	2	0	0	0	0	24	6	2	2	0	0	0	0

BUTTE, 1977

YEAR ROUND(259)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	15	4	4	0	0	0	0	1

HEATING SEASON(205)							
1	2	3	4	5	6	7	>7
10	3	4	0	0	0	0	1

BUTTE, 1978

YEAR ROUND(361)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	6	3	0	1	0	0	1

HEATING SEASON(227)							
1	2	3	4	5	6	7	>7
19	6	3	0	1	0	0	1

BUTTE, 1979

YEAR ROUND(302)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	18	3	0	0	0	1	0	0

HEATING SEASON(225)							
1	2	3	4	5	6	7	>7
18	3	0	0	0	1	0	0

BUTTE, 1980

YEAR ROUND(357)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	5	1	1	0	0	0	0

HEATING SEASON(231)							
1	2	3	4	5	6	7	>7
15	5	1	1	0	0	0	0

BUTTE, 1981

YEAR ROUND(268)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	31	6	2	0	0	0	0	0

HEATING SEASON(227)							
1	2	3	4	5	6	7	>7
28	5	2	0	0	0	0	0

BUTTE, 1982

YEAR ROUND(336)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	28	4	3	1	0	0	0	0

HEATING SEASON(225)							
1	2	3	4	5	6	7	>7
26	4	2	0	0	0	0	0

CHOTEAU NOT INSTRUMENTED IN 1977

CHOTEAU, 1978

YEAR ROUND(267)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	22	3	2	0	0	0	1	0

HEATING SEASON(150)								
1	2	3	4	5	6	7	>7
15	2	2	0	0	0	1	0

CHOTEAU, 1979

YEAR ROUND(325)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	20	1	1	0	0	0	1	0

HEATING SEASON(220)								
1	2	3	4	5	6	7	>7
19	1	1	0	0	0	1	0

CHOTEAU, 1980

YEAR ROUND(331)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	29	1	4	0	0	0	0	1

HEATING SEASON(218)								
1	2	3	4	5	6	7	>7
21	1	4	0	0	0	0	1

CHOTEAU, 1981

YEAR ROUND(351)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	17	7	2	0	0	0	0	0

HEATING SEASON(231)								
1	2	3	4	5	6	7	>7
16	7	2	0	0	0	0	0

CHOTEAU, 1982

YEAR ROUND(364)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	35	5	3	0	0	0	0	0

HEATING SEASON(230)								
1	2	3	4	5	6	7	>7
33	5	0	0	0	0	0	0

COLSTRIP, 1977

YEAR ROUND(107)									HEATING SEASON(89)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	7	1	0	0	0	0	0	0	7	1	0	0	0	0	0	0

COLSTRIP, 1978

YEAR ROUND(254)									HEATING SEASON(130)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	10	6	0	0	0	0	0	0	8	5	0	0	0	0	0	0

COLSTRIP, 1979

YEAR ROUND(154)									HEATING SEASON(122)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	14	3	1	0	0	0	0	0	13	3	1	0	0	0	0	0

COLSTRIP, 1980

YEAR ROUND(311)									HEATING SEASON(211)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	31	4	3	0	0	0	0	0	27	4	3	0	0	0	0	0

COLSTRIP, 1981

YEAR ROUND(334)									HEATING SEASON(214)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	14	8	0	1	0	0	0	0	11	8	0	1	0	0	0	0

COLSTRIP, 1982

YEAR ROUND(224)									HEATING SEASON(215)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	18	11	4	0	0	0	0	0	17	11	4	0	0	0	0	0

DILLON, 1977

YEAR ROUND(310)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	4	2	0	1	0	0	0

HEATING SEASON(189)							
1	2	3	4	5	6	7	>7
15	4	1	0	0	0	0	0

DILLON, 1978

YEAR ROUND(331)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	4	2	0	0	0	0	0

HEATING SEASON(212)							
1	2	3	4	5	6	7	>7
14	4	2	0	0	0	0	0

DILLON, 1979

YEAR ROUND(332)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	12	2	0	1	0	0	0	0

HEATING SEASON(204)							
1	2	3	4	5	6	7	>7
11	1	0	1	0	0	0	0

DILLON, 1980

YEAR ROUND(342)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	22	5	1	0	0	0	0	0

HEATING SEASON(225)							
1	2	3	4	5	6	7	>7
18	5	1	0	0	0	0	0

DILLON, 1981

YEAR ROUND(347)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	2	0	2	0	0	0	0

HEATING SEASON(213)							
1	2	3	4	5	6	7	>7
19	2	0	2	0	0	0	0

DILLON, 1982

YEAR ROUND(351)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	4	1	0	0	0	0	0

HEATING SEASON(227)							
1	2	3	4	5	6	7	>7
18	4	1	0	0	0	0	0

ENNIS NOT INSTRUMENTED IN 1977

ENNIS, 1978

YEAR ROUND(238)									HEATING SEASON(171)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	9	4	2	0	0	1	0	1		8	4	2	0	0	1	0	0

ENNIS, 1979

YEAR ROUND(330)									HEATING SEASON(213)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	18	6	0	1	0	0	0	0		17	5	0	1	0	0	0	0

ENNIS, 1980

YEAR ROUND(228)									HEATING SEASON(113)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	12	4	0	0	0	0	0	0		6	3	0	0	0	0	0	0

ENNIS, 1981

YEAR ROUND(309)									HEATING SEASON(181)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	17	4	1	1	1	0	0	0		14	3	1	1	1	0	0	0

ENNIS, 1982

YEAR ROUND(316)									HEATING SEASON(188)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	19	4	6	1	0	0	0	0		16	4	6	0	0	0	0	0

FORT BENTON NOT INSTRUMENTED IN 1977

FORT BENTON, 1978

YEAR ROUND(255)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	17	6	1	1	0	0	0	1

HEATING SEASON(154)								
1	2	3	4	5	6	7	>7
15	5	1	1	0	0	0	0

FORT BENTON, 1979

YEAR ROUND(353)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	28	2	3	1	2	0	0	0

HEATING SEASON(230)								
1	2	3	4	5	6	7	>7
26	2	3	1	2	0	0	0

FORT BENTON, 1980

YEAR ROUND(349)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	6	3	1	1	0	0	1

HEATING SEASON(215)								
1	2	3	4	5	6	7	>7
16	6	3	1	1	0	0	1

FORT BENTON, 1981

YEAR ROUND(364)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	28	8	1	0	0	0	0	0

HEATING SEASON(230)								
1	2	3	4	5	6	7	>7
24	8	1	0	0	0	0	0

FORT BENTON, 1982

YEAR ROUND(361)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	28	10	3	1	0	0	0	0

HEATING SEASON(230)								
1	2	3	4	5	6	7	>7
25	10	2	0	0	0	0	0

GLASGOW, 1977

YEAR ROUND(328)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	12	7	4	1	1	0	0	0

HEATING SEASON(206)								
1	2	3	4	5	6	7	>7	
8	7	3	1	1	0	0	0	

GLASGOW, 1978

YEAR ROUND(351)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	26	6	2	0	0	0	1	0

HEATING SEASON(223)								
1	2	3	4	5	6	7	>7	
22	6	1	0	0	0	1	0	

GLASGOW, 1979

YEAR ROUND(327)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	20	3	3	0	0	0	0	0

HEATING SEASON(221)								
1	2	3	4	5	6	7	>7	
17	3	3	0	0	0	0	0	

GLASGOW, 1980

YEAR ROUND(353)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	20	4	2	2	0	0	0	0

HEATING SEASON(226)								
1	2	3	4	5	6	7	>7	
18	4	2	2	0	0	0	0	

GLASGOW, 1981

YEAR ROUND(350)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	15	5	3	1	0	1	0	0

HEATING SEASON(226)								
1	2	3	4	5	6	7	>7	
13	4	3	1	0	1	0	0	

GLASGOW, 1982

YEAR ROUND(223)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	15	8	2	1	1	0	0	0

HEATING SEASON(180)								
1	2	3	4	5	6	7	>7	
15	7	2	1	1	0	0	0	

GLENDIVE, 1977

YEAR ROUND(304)									HEATING SEASON(202)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	19	8	2	0	1	0	0	0	14	7	2	0	1	0	0	0

GLENDIVE, 1978

YEAR ROUND(279)									HEATING SEASON(185)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	23	4	1	1	0	0	1	0	21	2	1	1	0	0	1	0

GLENDIVE, 1979

YEAR ROUND(159)									HEATING SEASON(47)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	4	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0

GLENDIVE, 1980

YEAR ROUND(252)									HEATING SEASON(176)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	18	3	1	2	0	0	0	0	16	2	1	2	0	0	0	0

GLENDIVE, 1981

YEAR ROUND(322)									HEATING SEASON(197)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	16	4	2	2	2	0	0	0	14	4	2	2	2	0	0	0

GLENDIVE, 1982

YEAR ROUND(270)									HEATING SEASON(142)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	19	8	2	1	0	0	0	0	12	6	2	1	0	0	0	0

GREAT FALLS, 1977

YEAR ROUND(328)									HEATING SEASON(194)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	21	2	1	2	1	0	0	0	17	1	0	2	1	0	0	0

GREAT FALLS, 1978

YEAR ROUND(343)									HEATING SEASON(215)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	24	5	4	1	0	0	0	0	19	5	3	1	0	0	0	0

GREAT FALLS, 1979

YEAR ROUND(361)									HEATING SEASON(227)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	24	2	2	0	0	0	0	0	23	2	2	0	0	0	0	0

GREAT FALLS, 1980

YEAR ROUND(362)									HEATING SEASON(228)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	30	4	6	0	0	0	0	1	23	4	6	0	0	0	0	1

GREAT FALLS, 1981

YEAR ROUND(362)									HEATING SEASON(228)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	28	5	3	0	0	0	0	0	24	5	3	0	0	0	0	0

GREAT FALLS, 1982

YEAR ROUND(364)									HEATING SEASON(230)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	29	8	3	1	0	0	0	0	27	8	2	0	0	0	0	0

HAMILTON, 1977

YEAR ROUND(224)									HEATING SEASON(146)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	10	4	2	0	1	0	0	1		8	3	2	0	1	0	0	1

HAMILTON, 1978

YEAR ROUND(227)									HEATING SEASON(210)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	15	9	3	3	2	0	0	0		14	9	2	3	2	0	0	0

HAMILTON, 1979

YEAR ROUND(331)									HEATING SEASON(228)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	20	8	2	0	0	1	1	0		18	8	2	0	0	1	1	0

HAMILTON, 1980

YEAR ROUND(328)									HEATING SEASON(224)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	23	6	1	0	0	1	0	1		19	6	1	0	0	1	0	1

HAMILTON, 1981

YEAR ROUND(348)									HEATING SEASON(215)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	20	9	5	1	1	0	0	0		18	9	5	1	1	0	0	0

HAMILTON, 1982

YEAR ROUND(350)									HEATING SEASON(226)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	26	8	3	1	0	0	0	1		23	7	3	1	0	0	0	1

HARLOWTON, 1977

YEAR ROUND(288)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	24	6	0	1	0	0	0	0

HEATING SEASON(185)								
1	2	3	4	5	6	7	>7	
18	6	0	1	0	0	0	0	

HARLOWTON, 1978

YEAR ROUND(253)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	13	2	1	1	0	0	0	1

HEATING SEASON(124)								
1	2	3	4	5	6	7	>7	
9	2	1	1	0	0	0	0	

HARLOWTON, 1979

YEAR ROUND(245)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	15	2	1	0	0	0	0	0

HEATING SEASON(151)								
1	2	3	4	5	6	7	>7	
14	1	1	0	0	0	0	0	

HARLOWTON, 1980

YEAR ROUND(260)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	22	6	1	0	0	0	0	0

HEATING SEASON(155)								
1	2	3	4	5	6	7	>7	
19	6	1	0	0	0	0	0	

HARLOWTON, 1981

YEAR ROUND(174)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	14	3	1	0	0	0	0	0

HEATING SEASON(135)								
1	2	3	4	5	6	7	>7	
12	3	1	0	0	0	0	0	

HARLOWTON, 1982

YEAR ROUND(269)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	3	3	0	1	0	0	0

HEATING SEASON(204)								
1	2	3	4	5	6	7	>7	
16	2	3	0	0	0	0	0	

HAVRE, 1977

YEAR ROUND(279)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	22	3	2	1	0	0	0	0

HEATING SEASON(160)								
1	2	3	4	5	6	7	>7	
12	3	2	1	0	0	0	0	

HAVRE, 1978

YEAR ROUND(313)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	28	9	2	1	1	0	0	1

HEATING SEASON(218)								
1	2	3	4	5	6	7	>7	
23	9	1	1	1	0	0	0	

HAVRE, 1979

YEAR ROUND(262)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	17	4	4	0	0	0	0	0

HEATING SEASON(209)								
1	2	3	4	5	6	7	>7	
15	4	4	0	0	0	0	0	

HAVRE, 1980

YEAR ROUND(318)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	24	6	1	1	0	0	0	1

HEATING SEASON(192)								
1	2	3	4	5	6	7	>7	
19	6	1	1	0	0	0	1	

HAVRE, 1981

YEAR ROUND(344)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	20	12	1	0	1	0	0	0

HEATING SEASON(231)								
1	2	3	4	5	6	7	>7	
16	12	1	0	1	0	0	0	

HAVRE, 1982

YEAR ROUND(339)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	30	8	5	1	0	0	0	0

HEATING SEASON(225)								
1	2	3	4	5	6	7	>7	
26	8	4	0	0	0	0	0	

HELENA, 1977

YEAR ROUND(321)									HEATING SEASON(215)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	18	13	1	0	1	0	0	0		16	9	1	0	1	0	0	0

HELENA, 1978

YEAR ROUND(353)									HEATING SEASON(223)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	22	6	4	1	0	0	0	0		18	6	3	1	0	0	0	0

HELENA, 1979

YEAR ROUND(349)									HEATING SEASON(224)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	24	3	1	0	0	0	0	0		22	3	1	0	0	0	0	0

HELENA, 1980

YEAR ROUND(268)									HEATING SEASON(205)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	23	6	2	0	0	0	0	1		16	6	2	0	0	0	0	1

HELENA, 1981

YEAR ROUND(302)									HEATING SEASON(172)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	18	6	1	2	0	0	0	0		15	5	1	2	0	0	0	0

HELENA, 1982

YEAR ROUND(141)									HEATING SEASON(138)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	11	6	5	0	0	0	0	0		11	6	5	0	0	0	0	0

JORDAN NOT INSTRUMENTED IN 1977

JORDAN, 1978

YEAR ROUND(230)									HEATING SEASON(100)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	14	4	2	0	1	1	0	0	11	3	1	0	1	1	0	0

JORDAN, 1979

YEAR ROUND(248)									HEATING SEASON(198)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	21	5	1	0	0	0	0	0	21	5	1	0	0	0	0	0

JORDAN, 1980

YEAR ROUND(332)									HEATING SEASON(226)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	17	10	2	0	0	0	0	0	15	9	2	0	0	0	0	0

JORDAN, 1981

YEAR ROUND(361)									HEATING SEASON(227)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	19	5	3	0	0	0	0	0	17	5	3	0	0	0	0	0

JORDAN, 1982

YEAR ROUND(363)									HEATING SEASON(231)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	24	8	2	1	1	0	0	0	18	6	2	1	1	0	0	0

KALISPELL, 1977

YEAR ROUND(290)									HEATING SEASON(178)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	31	0	5	2	0	0	0	0		24	0	5	2	0	0	0	0

KALISPELL, 1978

YEAR ROUND(361)									HEATING SEASON(229)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	32	6	5	3	0	1	0	0		22	6	5	3	0	1	0	0

KALISPELL, 1979

YEAR ROUND(356)									HEATING SEASON(223)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	11	8	5	0	4	1	2	1		10	8	5	0	4	1	2	1

KALISPELL, 1980

YEAR ROUND(345)									HEATING SEASON(212)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	21	12	1	1	0	0	0	2		17	9	1	1	0	0	0	2

KALISPELL, 1981

YEAR ROUND(303)									HEATING SEASON(208)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	17	6	2	2	3	1	0	2		14	6	2	2	3	1	0	2

KALISPELL, 1982

YEAR ROUND(364)									HEATING SEASON(230)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	27	6	2	2	1	2	1	2		21	6	2	1	1	2	1	2

LEWISTOWN, 1977

YEAR ROUND(298)									HEATING SEASON(184)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	23	5	0	1	0	0	0	0		15	5	0	1	0	0	0	0

LEWISTOWN, 1978

YEAR ROUND(265)									HEATING SEASON(175)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	18	4	2	0	0	0	0	1		15	3	2	0	0	0	0	1

LEWISTOWN, 1979

YEAR ROUND(338)									HEATING SEASON(221)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	27	4	0	0	0	0	0	0		27	4	0	0	0	0	0	0

LEWISTOWN, 1980

YEAR ROUND(362)									HEATING SEASON(228)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	28	6	2	0	0	0	1	0		22	6	2	0	0	0	1	0

LEWISTOWN, 1981

YEAR ROUND(341)									HEATING SEASON(229)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	24	8	0	0	0	0	0	0		20	8	0	0	0	0	0	0

LEWISTOWN, 1982

YEAR ROUND(340)									HEATING SEASON(206)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	24	6	5	0	0	0	0	0		18	6	4	0	0	0	0	0

LIBBY, 1977

YEAR ROUND(224)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	13	5	0	0	0	0	0	0

HEATING SEASON(131)							
1	2	3	4	5	6	7	>7
9	4	0	0	0	0	0	0

LIBBY, 1978

YEAR ROUND(303)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	26	6	1	0	1	1	0	0

HEATING SEASON(182)							
1	2	3	4	5	6	7	>7
17	6	1	0	1	1	0	0

LIBBY, 1979

YEAR ROUND(334)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	14	4	3	2	0	2	0	3

HEATING SEASON(202)							
1	2	3	4	5	6	7	>7
12	4	3	2	0	2	0	3

LIBBY, 1980

YEAR ROUND(339)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	13	13	2	3	1	1	2	1

HEATING SEASON(207)							
1	2	3	4	5	6	7	>7
7	10	2	3	1	1	2	1

LIBBY, 1981

YEAR ROUND(356)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	7	2	2	3	2	1	2

HEATING SEASON(222)							
1	2	3	4	5	6	7	>7
16	7	2	2	3	2	1	2

LIBBY, 1982

YEAR ROUND(319)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	22	4	2	2	2	1	0	3

HEATING SEASON(200)							
1	2	3	4	5	6	7	>7
16	4	2	2	2	1	0	3

LIVINGSTON NOT INSTRUMENTED IN 1977

LIVINGSTON, 1978

YEAR ROUND(211)									HEATING SEASON(128)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	11	5	0	0	0	0	0	0	7	4	0	0	0	0	0	0

LIVINGSTON, 1979

YEAR ROUND(172)									HEATING SEASON(136)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	21	2	2	1	0	0	0	0	21	2	2	1	0	0	0	0

LIVINGSTON, 1980

YEAR ROUND(263)									HEATING SEASON(187)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	22	5	3	1	1	0	0	0	19	5	3	1	1	0	0	0

LIVINGSTON, 1981

YEAR ROUND(198)									HEATING SEASON(126)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	16	4	0	0	0	0	0	0	13	4	0	0	0	0	0	0

LIVINGSTON, 1982

YEAR ROUND(136)									HEATING SEASON(54)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	11	4	0	2	1	0	0	0	9	4	0	2	0	0	0	0

MILES CITY, 1977

YEAR ROUND(340)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	25	7	1	1	0	0	0	1

HEATING SEASON(208)							
1	2	3	4	5	6	7	>7
18	7	1	1	0	0	0	0

MILES CITY, 1978

YEAR ROUND(313)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	24	4	4	0	1	0	0	0

HEATING SEASON(228)							
1	2	3	4	5	6	7	>7
23	3	3	0	1	0	0	0

MILES CITY, 1979

YEAR ROUND(324)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	2	1	0	0	0	0	0

HEATING SEASON(225)							
1	2	3	4	5	6	7	>7
18	2	1	0	0	0	0	0

MILES CITY, 1980

YEAR ROUND(363)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	30	5	3	0	1	0	0	0

HEATING SEASON(229)							
1	2	3	4	5	6	7	>7
23	5	3	0	1	0	0	0

MILES CITY, 1981

YEAR ROUND(331)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	8	0	1	0	0	0	0

HEATING SEASON(199)							
1	2	3	4	5	6	7	>7
15	8	0	1	0	0	0	0

MILES CITY, 1982

YEAR ROUND(349)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	26	11	5	0	1	0	0	0

HEATING SEASON(231)							
1	2	3	4	5	6	7	>7
18	10	4	0	1	0	0	0

MISSOULA, 1977

YEAR ROUND(319)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	18	8	2	1	1	0	0	1

HEATING SEASON(195)							
1	2	3	4	5	6	7	>7
14	7	1	1	1	0	0	1

MISSOULA, 1978

YEAR ROUND(346)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	23	6	5	2	1	0	1	0

HEATING SEASON(212)							
1	2	3	4	5	6	7	>7
12	5	4	2	1	0	1	0

MISSOULA, 1979

YEAR ROUND(352)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	11	3	3	0	0	0	1

HEATING SEASON(218)							
1	2	3	4	5	6	7	>7
19	10	3	3	0	0	0	1

MISSOULA, 1980

YEAR ROUND(363)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	27	9	4	1	1	1	0	1

HEATING SEASON(231)							
1	2	3	4	5	6	7	>7
22	8	3	1	1	1	0	1

MISSOULA, 1981

YEAR ROUND(220)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	5	3	3	1	1	0	2

HEATING SEASON(198)							
1	2	3	4	5	6	7	>7
17	5	3	3	1	1	0	2

MISSOULA, 1982

YEAR ROUND(339)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	21	6	6	2	0	2	0	1

HEATING SEASON(221)							
1	2	3	4	5	6	7	>7
18	6	5	2	0	2	0	1

PLENTYWOOD NOT INSTRUMENTED IN 1977

PLENTYWOOD, 1978

YEAR ROUND(289)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	17	7	0	1	2	1	0	0

HEATING SEASON(173)								
1	2	3	4	5	6	7	>7
14	5	0	1	2	1	0	0

PLENTYWOOD, 1979

YEAR ROUND(334)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	6	3	0	0	0	0	0

HEATING SEASON(205)								
1	2	3	4	5	6	7	>7
17	6	3	0	0	0	0	0

PLENTYWOOD, 1980

YEAR ROUND(354)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	23	9	0	0	0	0	0	0

HEATING SEASON(221)								
1	2	3	4	5	6	7	>7
21	6	0	0	0	0	0	0

PLENTYWOOD, 1981

YEAR ROUND(352)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	15	7	3	1	0	0	2	0

HEATING SEASON(228)								
1	2	3	4	5	6	7	>7
12	6	3	1	0	0	2	0

PLENTYWOOD, 1982

YEAR ROUND(216)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	5	3	1	1	0	0	0

HEATING SEASON(186)								
1	2	3	4	5	6	7	>7
19	5	2	1	1	0	0	0

POLSON, 1977

YEAR ROUND(315)									HEATING SEASON(181)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	23	6	4	0	1	0	0	0		18	6	3	0	1	0	0	0

POLSON, 1978

YEAR ROUND(361)									HEATING SEASON(231)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	21	6	2	4	1	2	1	0		14	6	2	3	1	2	1	0

POLSON, 1979

YEAR ROUND(271)									HEATING SEASON(216)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	19	3	2	5	1	3	1	0		18	3	2	5	1	3	1	0

POLSON, 1980

YEAR ROUND(362)									HEATING SEASON(229)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	33	13	2	1	1	1	0	1		26	12	2	1	1	1	0	1

POLSON, 1981

YEAR ROUND(357)									HEATING SEASON(223)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	25	7	2	2	2	1	0	2		19	7	2	2	2	1	0	2

POLSON, 1982

YEAR ROUND(346)									HEATING SEASON(226)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7		1	2	3	4	5	6	7	>7
OCCURRENCES	14	7	4	4	0	3	1	2		13	7	3	3	0	3	1	2

RED LODGE NOT INSTRUMENTED IN 1977

RED LODGE, 1978

YEAR ROUND(303)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	14	7	2	0	0	0	0	0

HEATING SEASON(177)							
1	2	3	4	5	6	7	>7
9	5	2	0	0	0	0	0

RED LODGE, 1979

YEAR ROUND(360)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	19	5	2	0	0	0	0	0

HEATING SEASON(229)							
1	2	3	4	5	6	7	>7
18	3	2	0	0	0	0	0

RED LODGE, 1980

YEAR ROUND(364)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	24	8	1	0	0	0	0	0

HEATING SEASON(230)							
1	2	3	4	5	6	7	>7
21	7	1	0	0	0	0	0

RED LODGE, 1981

YEAR ROUND(353)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	4	0	0	0	0	0	0

HEATING SEASON(230)							
1	2	3	4	5	6	7	>7
14	3	0	0	0	0	0	0

RED LODGE, 1982

YEAR ROUND(361)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	25	6	0	0	0	0	0	0

HEATING SEASON(229)							
1	2	3	4	5	6	7	>7
20	4	0	0	0	0	0	0

SIDNEY NOT INSTRUMENTED IN 1977

SIDNEY, 1978

YEAR ROUND(147)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	12	6	0	2	0	0	0	0

HEATING SEASON(129)							
1	2	3	4	5	6	7	>7
12	5	0	2	0	0	0	0

SIDNEY, 1979

YEAR ROUND(344)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	23	3	2	0	1	0	0	0

HEATING SEASON(220)							
1	2	3	4	5	6	7	>7
22	3	2	0	1	0	0	0

SIDNEY, 1980

YEAR ROUND(257)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	23	6	2	0	0	0	0	0

HEATING SEASON(150)							
1	2	3	4	5	6	7	>7
17	4	2	0	0	0	0	0

SIDNEY, 1981

YEAR ROUND(148)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	10	4	0	0	0	0	0	0

HEATING SEASON(134)							
1	2	3	4	5	6	7	>7
8	4	0	0	0	0	0	0

SIDNEY, 1982

YEAR ROUND(156)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	13	4	2	2	4	0	0	0

HEATING SEASON(156)							
1	2	3	4	5	6	7	>7
13	4	2	2	4	0	0	0

THOMPSON FALLS NOT INSTRUMENTED IN 1977

THOMPSON FALLS, 1978

YEAR ROUND(238)									HEATING SEASON(164)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	17	5	3	3	2	0	0	0	13	4	3	3	2	0	0	0

THOMPSON FALLS, 1979

YEAR ROUND(157)									HEATING SEASON(135)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	11	4	3	0	1	0	0	0	11	4	3	0	1	0	0	0

THOMPSON FALLS, 1980

YEAR ROUND(273)									HEATING SEASON(172)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	18	6	5	2	2	0	0	1	13	6	5	2	2	0	0	1

THOMPSON FALLS, 1981

YEAR ROUND(260)									HEATING SEASON(135)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	14	3	2	2	0	0	1	0	9	3	2	2	0	0	1	0

THOMPSON FALLS, 1982

YEAR ROUND(72)									HEATING SEASON(61)							
CLOUDY DAYS	1	2	3	4	5	6	7	>7	1	2	3	4	5	6	7	>7
OCCURRENCES	2	0	1	0	0	0	0	1	1	0	1	0	0	0	0	1

WEST YELLOWSTONE, 1977

YEAR ROUND(271)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	3	1	0	0	0	0	0

HEATING SEASON(180)								
1	2	3	4	5	6	7	>7	
13	3	1	0	0	0	0	0	

WEST YELLOWSTONE, 1978

YEAR ROUND(297)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	11	5	5	1	0	0	1	0

HEATING SEASON(216)								
1	2	3	4	5	6	7	>7	
9	5	5	1	0	0	1	0	

WEST YELLOWSTONE, 1979

YEAR ROUND(309)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	9	0	0	0	0	0	0

HEATING SEASON(184)								
1	2	3	4	5	6	7	>7	
14	9	0	0	0	0	0	0	

WEST YELLOWSTONE, 1980

YEAR ROUND(336)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	16	4	2	3	1	1	0	1

HEATING SEASON(222)								
1	2	3	4	5	6	7	>7	
12	4	2	3	1	1	0	1	

WEST YELLOWSTONE, 1981

YEAR ROUND(302)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	17	4	1	2	1	0	0	0

HEATING SEASON(183)								
1	2	3	4	5	6	7	>7	
11	4	1	2	1	0	0	0	

WEST YELLOWSTONE, 1982

YEAR ROUND(64)								
CLOUDY DAYS	1	2	3	4	5	6	7	>7
OCCURRENCES	4	3	1	0	0	0	0	0

HEATING SEASON(5)								
1	2	3	4	5	6	7	>7	
1	0	1	0	0	0	0	0	

SECTION 7

CLIMATOLOGICAL DATA

alphabetical by station

Note: There are two data tables for each station; one in degrees Fahrenheit and the other in Celsius. These data are long-term averages reproduced from National Weather Service records.

CLIMATOLOGICAL DATA FOR

ANACONDA

LAT: 46.12 LONG: 112.95 ELEV: 1620(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.4	-2.9	-1.4	4.2	9.3	13.1	18.7	17.8	12.4	7.2	.1	-3.4
DAILY MAXIMUM	-1.6	.4	3.9	9.7	15.3	19.9	26.1	24.9	18.7	12.0	4.2	.2
DAILY MINIMUM	-9.6	-8.3	-5.8	-.9	3.4	7.3	11.5	10.5	6.2	1.6	-4.0	-7.4
EXTREME MAXIMUM	12.2	14.4	19.4	28.9	32.2	35.0	37.2	37.8	33.3	27.8	21.7	15.0
EXTREME MINIMUM	-34.4	-37.2	-27.8	-22.8	-8.3	-4.4	.0	-2.2	-15.0	-22.2	-31.7	-33.9
HEATING DEGREE DAYS(18C)	735	595	613	425	278	163	40	62	191	346	548	675

CLIMATOLOGICAL DATA FOR

ANACONDA

LAT: 46.12 LONG: 112.95 ELEV: 5331(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	22.3	26.7	29.4	39.5	48.8	55.6	65.6	64.1	54.4	44.9	32.1	25.8
DAILY MAXIMUM	29.2	32.8	39.0	49.5	59.5	67.8	79.0	76.9	65.7	53.6	39.5	32.3
DAILY MINIMUM	14.7	17.0	21.5	30.3	38.1	45.1	52.7	50.9	43.1	34.8	24.8	18.6
EXTREME MAXIMUM	54.0	58.0	67.0	84.0	90.0	95.0	99.0	100.0	92.0	82.0	71.0	59.0
EXTREME MINIMUM	-30.0	-35.0	-18.0	-9.0	17.0	24.0	32.0	28.0	5.0	-8.0	-25.0	-29.0
HEATING DEGREE DAYS(65F)	1324	1072	1104	765	502	294	72	112	344	623	987	1215

CLIMATOLOGICAL DATA FOR

BILLINGS

LAT: 45.78 LONG: 108.50 ELEV: 947(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-4.9	-1.3	1.6	8.3	13.4	17.3	21.9	20.8	15.1	9.8	2.4	-2.3
DAILY MAXIMUM	2.3	5.1	9.0	16.8	21.9	25.4	31.4	30.6	24.9	18.6	9.2	5.2
DAILY MINIMUM	-11.4	-9.6	-5.7	-.1	5.1	8.9	12.3	10.7	5.7	.9	-4.9	-8.3
EXTREME MAXIMUM	22.2	22.8	26.7	32.2	35.0	37.8	42.2	39.4	37.2	32.2	22.8	22.8
EXTREME MINIMUM	-37.2	-35.0	-29.4	-13.9	-10.0	-1.1	3.9	.0	-5.0	-10.6	-33.3	-30.6
HEATING DEGREE DAYS(18C)	720	548	518	301	160	67	6	12	122	263	476	640

CLIMATOLOGICAL DATA FOR

BILLINGS

LAT: 45.78 LONG: 108.50 ELEV: 3117(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	23.2	29.7	34.9	46.9	56.1	63.2	71.4	69.5	59.1	49.7	36.4	27.8
DAILY MAXIMUM	36.1	41.1	48.2	62.3	71.4	77.8	88.6	87.0	76.9	65.5	48.5	41.3
DAILY MINIMUM	11.5	14.8	21.7	31.9	41.2	48.1	54.1	51.2	42.2	33.6	23.2	17.0
EXTREME MAXIMUM	72.0	73.0	80.0	90.0	95.0	100.0	108.0	103.0	99.0	90.0	73.0	73.0
EXTREME MINIMUM	-35.0	-31.0	-21.0	7.0	14.0	30.0	39.0	32.0	23.0	13.0	-28.0	-23.0
HEATING DEGREE DAYS(65F)	1296	988	933	543	288	121	11	23	221	474	858	1153

CLIMATOLOGICAL DATA FOR

BOZEMAN

LAT: 45.67 LONG: 111.03 ELEV: 1445(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.4	-3.4	-1.0	5.6	10.5	14.2	19.1	18.3	13.1	7.8	.1	-3.8
DAILY MAXIMUM	-.7	2.1	5.0	12.1	17.4	21.2	27.5	26.8	20.8	14.8	5.8	1.6
DAILY MINIMUM	-12.2	-9.0	-7.1	-.9	3.6	7.2	10.6	9.7	5.3	.8	-5.6	-9.2
EXTREME MAXIMUM	14.4	16.7	21.1	27.2	31.7	32.8	36.7	37.2	35.0	27.8	21.1	15.0
EXTREME MINIMUM	-37.8	-33.9	-30.6	-16.7	-8.9	-3.3	.0	-1.7	-8.9	-12.8	-32.2	-33.9
HEATING DEGREE DAYS(18C)	762	614	596	377	238	128	25	38	160	322	542	682

CLIMATOLOGICAL DATA FOR

BOZEMAN

LAT: 45.67 LONG: 111.03 ELEV: 4754(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	20.4	25.9	30.2	42.1	50.9	57.6	66.3	64.9	55.6	46.1	32.2	25.2
DAILY MAXIMUM	30.7	35.8	41.0	53.7	63.3	70.2	81.5	80.3	69.5	58.7	42.4	34.9
DAILY MINIMUM	10.1	15.8	19.2	30.4	38.5	44.9	51.1	49.4	41.5	33.4	21.9	15.5
EXTREME MAXIMUM	58.0	62.0	70.0	81.0	89.0	91.0	98.0	99.0	95.0	82.0	70.0	59.0
EXTREME MINIMUM	-36.0	-29.0	-23.0	2.0	16.0	26.0	32.0	29.0	16.0	9.0	-26.0	-29.0
HEATING DEGREE DAYS(65F)	1372	1106	1074	680	429	232	45	70	288	581	976	1229

CLIMATOLOGICAL DATA FOR

BROWNING

LAT: 48.55 LONG: 113.02 ELEV: 1356(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-7.8	-4.7	-2.8	3.7	9.0	12.6	16.8	15.8	11.3	6.7	-.7	-4.7
DAILY MAXIMUM	-1.7	-.5	3.4	10.6	16.4	20.0	25.6	24.4	18.5	12.6	4.5	.4
DAILY MINIMUM	-13.1	-12.2	-8.8	-2.8	1.8	5.1	7.6	6.5	2.8	-1.1	-6.9	-10.3
EXTREME MAXIMUM	18.9	20.0	22.2	32.8	33.9	36.7	37.2	36.7	34.4	28.3	22.2	20.6
EXTREME MINIMUM	-48.9	-43.3	-38.9	-25.6	-17.2	-6.1	-4.4	-5.0	-17.8	-27.2	-39.4	-43.9
HEATING DEGREE DAYS(18C)	809	643	654	438	289	175	61	92	219	360	571	715

CLIMATOLOGICAL DATA FOR

BROWNING

LAT: 48.55 LONG: 113.02 ELEV: 4462(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	18.0	23.6	27.0	38.7	48.2	54.7	62.3	60.5	52.3	44.1	30.7	23.5
DAILY MAXIMUM	29.0	31.1	38.1	51.0	61.5	68.0	78.0	76.0	65.3	54.6	40.1	32.8
DAILY MINIMUM	8.4	10.1	16.2	26.9	35.3	41.2	45.6	43.7	37.0	30.1	19.5	13.4
EXTREME MAXIMUM	66.0	68.0	72.0	91.0	93.0	98.0	99.0	98.0	94.0	83.0	72.0	69.0
EXTREME MINIMUM	-56.0	-46.0	-38.0	-14.0	1.0	21.0	24.0	23.0	.0	-17.0	-39.0	-47.0
HEATING DEGREE DAYS(65F)	1457	1159	1178	789	521	315	111	167	395	648	1029	1287

CLIMATOLOGICAL DATA FOR

BUTTE

LAT: 46.00 LONG: 112.50 ELEV: 1749(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-9.4	-6.2	-3.6	3.2	8.2	12.2	16.8	15.7	10.3	5.1	-2.3	-7.1
DAILY MAXIMUM	-2.3	.4	3.9	10.5	15.9	19.9	26.7	25.6	19.7	13.5	4.6	.3
DAILY MINIMUM	-16.9	-14.7	-10.2	-3.5	.8	4.5	7.3	5.8	1.6	-2.9	-9.4	-13.5
EXTREME MAXIMUM	12.2	15.6	17.8	26.1	31.1	33.9	37.8	37.2	32.8	28.3	20.0	16.7
EXTREME MINIMUM	-44.4	-46.7	-37.8	-25.0	-11.1	-5.0	-1.7	-3.3	-11.1	-28.3	-41.1	-38.3
HEATING DEGREE DAYS(18C)	859	686	678	455	313	187	66	92	242	411	618	788

CLIMATOLOGICAL DATA FOR

BUTTE

LAT: 46.00 LONG: 112.50 ELEV: 5755(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	15.1	20.9	25.6	37.7	46.8	53.9	62.2	60.3	50.6	41.1	27.9	19.2
DAILY MAXIMUM	27.8	32.7	39.1	50.9	60.7	67.9	80.0	78.0	67.5	56.3	40.3	32.5
DAILY MINIMUM	1.5	5.5	13.7	25.7	33.5	40.1	45.1	42.5	34.8	26.8	15.0	7.7
EXTREME MAXIMUM	54.0	60.0	64.0	79.0	88.0	93.0	100.0	99.0	91.0	83.0	68.0	62.0
EXTREME MINIMUM	-48.0	-52.0	-36.0	-13.0	12.0	23.0	29.0	26.0	12.0	-19.0	-42.0	-37.0
HEATING DEGREE DAYS(65F)	1547	1235	1221	819	564	337	119	166	437	741	1113	1420

CLIMATOLOGICAL DATA FOR

CHOTEAU

LAT: 47.82 LONG: 112.20 ELEV: 1155(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.1	-2.9	-.8	5.7	10.9	14.8	19.1	18.0	12.8	8.3	1.0	-3.1
DAILY MAXIMUM	.7	2.6	6.6	12.9	18.6	22.4	28.2	27.1	20.9	15.5	7.4	3.6
DAILY MINIMUM	-13.2	-11.8	-7.7	-2.2	2.7	6.8	9.6	7.9	3.7	-.5	-6.6	-9.6
EXTREME MAXIMUM	18.9	21.1	27.8	29.4	33.3	36.1	40.6	41.1	35.6	30.6	25.0	22.2
EXTREME MINIMUM	-42.2	-45.6	-37.8	-26.7	-13.3	-2.2	.6	-1.7	-20.6	-26.1	-34.4	-38.9
HEATING DEGREE DAYS(18C)	756	595	594	378	230	117	26	47	177	310	520	665

CLIMATOLOGICAL DATA FOR

CHOTEAU

LAT: 47.82 LONG: 112.20 ELEV: 3800(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	21.1	26.7	30.5	42.3	51.6	58.7	66.3	64.4	55.0	47.0	33.8	26.4
DAILY MAXIMUM	33.2	36.6	43.8	55.2	65.4	72.3	82.7	80.8	69.6	59.9	45.4	38.4
DAILY MINIMUM	8.2	10.8	18.2	28.0	36.9	44.2	49.2	46.3	38.7	31.1	20.1	14.8
EXTREME MAXIMUM	66.0	70.0	82.0	85.0	92.0	97.0	105.0	106.0	96.0	87.0	77.0	72.0
EXTREME MINIMUM	-44.0	-50.0	-36.0	-16.0	8.0	28.0	33.0	29.0	-5.0	-15.0	-30.0	-38.0
HEATING DEGREE DAYS(65F)	1361	1072	1070	681	415	212	47	85	320	558	936	1197

CLIMATOLOGICAL DATA FOR

COLSTRIP

LAT: 45.88 LONG: 106.63 ELEV: 772(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.1	-2.8	.2	7.1	12.4	17.1	21.9	21.2	15.0	9.2	1.3	-3.6
DAILY MAXIMUM	1.2	4.3	7.7	15.2	20.7	25.3	31.8	31.2	24.4	18.2	8.6	3.4
DAILY MINIMUM	-13.5	-10.1	-7.3	-1.1	4.1	8.7	12.1	11.2	5.6	.2	-6.1	-10.7
EXTREME MAXIMUM	19.4	21.1	26.7	30.6	35.6	38.9	41.7	43.9	38.9	34.4	26.1	21.7
EXTREME MINIMUM	-40.0	-35.0	-33.3	-16.1	-10.6	-2.2	1.1	.6	-7.8	-13.9	-35.6	-37.2
HEATING DEGREE DAYS(18C)	753	585	556	346	177	58	6	13	112	277	508	667

CLIMATOLOGICAL DATA FOR

COLSTRIP

LAT: 45.88 LONG: 106.63 ELEV: 2540(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	21.0	26.9	32.3	44.7	54.3	62.7	71.5	70.1	59.0	48.6	34.3	25.5
DAILY MAXIMUM	34.2	39.8	45.8	59.3	69.2	77.6	89.2	88.1	75.9	64.8	47.5	38.2
DAILY MINIMUM	7.7	13.9	18.9	30.1	39.4	47.7	53.8	52.1	42.0	32.4	21.1	12.8
EXTREME MAXIMUM	67.0	70.0	80.0	87.0	96.0	102.0	107.0	111.0	102.0	94.0	79.0	71.0
EXTREME MINIMUM	-40.0	-31.0	-28.0	3.0	13.0	28.0	34.0	33.0	18.0	7.0	-32.0	-35.0
HEATING DEGREE DAYS(65F)	1356	1053	1001	624	319	105	12	24	203	500	915	1202

CLIMATOLOGICAL DATA FOR

DILLON

LAT: 45.25 LONG: 112.63 ELEV: 1537(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.4	-2.6	-.3	5.6	10.4	14.2	18.4	17.4	12.6	7.8	.8	-3.5
DAILY MAXIMUM	1.2	3.5	7.3	13.3	18.6	23.2	28.1	27.3	21.9	16.3	8.1	2.9
DAILY MINIMUM	-11.3	-9.3	-5.8	-1.2	2.7	5.9	8.7	7.3	2.9	-.7	-5.8	-9.4
EXTREME MAXIMUM	15.6	18.3	23.3	28.9	32.8	34.4	37.2	37.8	33.9	30.0	26.1	18.3
EXTREME MINIMUM	-37.8	-40.0	-32.2	-18.3	-9.4	-3.9	-1.1	-3.9	-12.8	-25.0	-35.0	-37.2
HEATING DEGREE DAYS(18C)	737	585	577	381	246	130	27	55	177	325	525	676

CLIMATOLOGICAL DATA FOR

DILLON

LAT: 45.25 LONG: 112.63 ELEV: 5057(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	22.2	27.4	31.5	42.1	50.7	57.5	65.1	63.4	54.7	46.1	33.5	25.7
DAILY MAXIMUM	34.2	38.3	45.2	55.9	65.4	73.8	82.6	81.1	71.4	61.4	46.5	37.2
DAILY MINIMUM	11.7	15.3	21.5	29.9	36.9	42.7	47.7	45.1	37.2	30.7	21.5	15.1
EXTREME MAXIMUM	60.0	65.0	74.0	84.0	91.0	94.0	99.0	100.0	93.0	86.0	79.0	65.0
EXTREME MINIMUM	-36.0	-40.0	-26.0	-1.0	15.0	25.0	30.0	25.0	9.0	-13.0	-31.0	-35.0
HEATING DEGREE DAYS(65F)	1327	1053	1039	687	443	235	50	100	319	586	945	1218

CLIMATOLOGICAL DATA FOR

ENNIS

LAT: 45.35 LONG: 111.73 ELEV: 1497(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.2	-2.5	-.4	5.4	10.2	13.9	18.2	17.3	12.3	7.7	1.0	-2.9
DAILY MAXIMUM	-.1	2.2	6.3	13.0	18.6	22.9	28.2	27.2	21.7	15.3	6.7	2.0
DAILY MINIMUM	-11.3	-9.6	-6.5	-2.1	2.1	5.7	8.5	7.2	3.1	-.6	-5.6	-8.6
EXTREME MAXIMUM	14.4	16.7	24.4	27.8	34.4	36.1	37.8	36.1	33.3	30.0	21.7	20.0
EXTREME MINIMUM	-41.7	-41.7	-33.9	-21.7	-9.4	-4.4	.0	-2.8	-11.1	-23.3	-32.8	-38.3
HEATING DEGREE DAYS(18C)	730	583	580	386	251	138	37	52	186	330	520	657

CLIMATOLOGICAL DATA FOR

ENNIS

LAT: 45.35 LONG: 111.73 ELEV: 4927(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	22.6	27.5	31.3	41.8	50.4	57.0	64.7	63.1	54.1	45.8	33.8	26.8
DAILY MAXIMUM	31.8	36.0	43.4	55.4	65.5	73.3	82.8	81.0	71.0	59.5	44.0	35.6
DAILY MINIMUM	11.6	14.7	20.3	28.3	35.8	42.3	47.3	44.9	37.5	30.9	21.9	16.5
EXTREME MAXIMUM	58.0	62.0	76.0	82.0	94.0	97.0	100.0	97.0	92.0	86.0	71.0	68.0
EXTREME MINIMUM	-43.0	-43.0	-29.0	-7.0	15.0	24.0	32.0	27.0	12.0	-10.0	-27.0	-37.0
HEATING DEGREE DAYS(65F)	1314	1050	1045	696	453	249	68	94	336	595	936	1184

CLIMATOLOGICAL DATA FOR

FORT BENTON

LAT: 47.80 LONG: 110.67 ELEV: 790(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-7.3	-3.3	-.1	7.3	12.8	16.7	20.9	20.0	14.1	8.8	.9	-4.3
DAILY MAXIMUM	.1	1.6	6.6	15.4	20.2	23.8	29.6	28.5	22.6	17.1	7.2	3.1
DAILY MINIMUM	-12.9	-12.0	-7.1	-.3	4.9	9.2	11.9	10.5	5.7	.7	-5.6	-9.4
EXTREME MAXIMUM	22.2	21.1	27.8	33.9	34.4	42.2	43.9	42.8	38.3	33.3	25.6	22.8
EXTREME MINIMUM	-50.0	-42.8	-41.1	-21.1	-10.0	-2.8	-.6	-2.8	-12.8	-21.1	-37.9	-50.6
HEATING DEGREE DAYS(18C)	806	605	571	330	176	78	8	18	140	294	523	701

CLIMATOLOGICAL DATA FOR

FORT BENTON

LAT: 47.80 LONG: 110.67 ELEV: 2600(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	18.8	26.1	31.8	45.2	55.0	62.0	69.7	68.0	57.3	47.9	33.6	24.3
DAILY MAXIMUM	32.1	34.9	43.9	59.7	68.4	74.9	85.3	83.3	72.7	62.7	45.0	37.6
DAILY MINIMUM	8.7	10.4	19.2	31.5	40.9	48.6	53.4	50.9	42.2	33.2	21.9	15.1
EXTREME MAXIMUM	72.0	70.0	82.0	93.0	94.0	108.0	111.0	109.0	101.0	92.0	78.0	73.0
EXTREME MINIMUM	-58.0	-45.0	-42.0	-6.0	14.0	27.0	31.0	27.0	9.0	-6.0	-36.0	-59.0
HEATING DEGREE DAYS(65F)	1451	1089	1029	594	317	141	16	33	253	530	942	1262

CLIMATOLOGICAL DATA FOR

GLASGOW

LAT: 48.20 LONG: 106.63 ELEV: 636(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-11.9	-9.7	-2.0	6.9	13.1	17.6	22.3	20.5	14.0	7.5	-2.2	-9.0
DAILY MAXIMUM	-6.9	-4.6	3.0	13.2	20.2	24.4	30.4	28.6	21.4	14.4	3.3	-3.9
DAILY MINIMUM	-17.0	-14.9	-7.0	.6	5.9	10.7	14.2	12.4	6.6	.6	-7.8	-14.1
EXTREME MAXIMUM	16.1	15.0	25.6	33.9	38.9	36.1	42.2	42.2	38.9	35.6	21.1	17.8
EXTREME MINIMUM	-45.6	-36.1	-33.9	-20.0	-8.9	2.2	3.9	.6	-6.1	-13.9	-29.4	-35.0
HEATING DEGREE DAYS(18C)	938	785	630	343	183	72	8	18	145	336	616	847

CLIMATOLOGICAL DATA FOR

GLASGOW

LAT: 48.20 LONG: 106.63 ELEV: 2095(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	10.5	14.5	28.4	44.4	55.5	63.6	72.2	68.9	57.2	45.5	28.0	15.8
DAILY MAXIMUM	19.6	23.7	37.4	55.7	68.4	75.9	86.7	83.5	70.5	57.9	37.9	24.9
DAILY MINIMUM	1.4	5.2	19.4	33.0	42.6	51.2	57.6	54.3	43.8	33.1	18.0	6.6
EXTREME MAXIMUM	61.0	59.0	78.0	93.0	102.0	97.0	108.0	108.0	102.0	96.0	70.0	64.0
EXTREME MINIMUM	-50.0	-33.0	-29.0	-4.0	16.0	36.0	39.0	33.0	21.0	7.0	-21.0	-31.0
HEATING DEGREE DAYS(65F)	1690	1414	1135	618	330	131	15	34	262	605	1110	1525

CLIMATOLOGICAL DATA FOR

GLENDIVE

LAT: 47.12 LONG: 104.73 ELEV: 629(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-9.5	-6.4	-.9	8.0	14.3	18.8	23.3	22.3	15.7	9.7	.6	-5.6
DAILY MAXIMUM	-3.7	-1.8	5.2	15.5	21.8	26.4	31.8	30.7	23.8	16.7	6.1	-.6
DAILY MINIMUM	-16.1	-14.8	-8.1	.3	6.1	11.3	14.6	12.8	6.7	.6	-6.6	-12.5
EXTREME MAXIMUM	17.2	22.8	29.4	35.6	40.0	42.8	47.2	45.0	40.0	35.0	24.4	22.2
EXTREME MINIMUM	-44.4	-45.6	-36.7	-21.1	-8.9	-1.7	2.2	.0	-8.9	-25.0	-32.2	-40.0
HEATING DEGREE DAYS(18C)	862	692	596	313	136	50	4	7	113	268	531	742

CLIMATOLOGICAL DATA FOR

GLENDIVE

LAT: 47.12 LONG: 104.73 ELEV: 2071(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	14.9	20.5	30.4	46.4	57.8	65.9	74.0	72.2	60.2	49.4	33.1	21.9
DAILY MAXIMUM	25.3	28.8	41.4	59.9	71.3	79.6	89.2	87.3	74.9	62.1	43.0	31.0
DAILY MINIMUM	3.0	5.3	17.4	32.5	43.0	52.3	58.2	55.0	44.1	33.0	20.2	9.5
EXTREME MAXIMUM	63.0	73.0	85.0	96.0	104.0	109.0	117.0	113.0	104.0	95.0	76.0	72.0
EXTREME MINIMUM	-48.0	-50.0	-34.0	-6.0	16.0	29.0	36.0	32.0	16.0	-13.0	-26.0	-40.0
HEATING DEGREE DAYS(65F)	1553	1246	1073	564	246	90	8	13	204	484	957	1336

CLIMATOLOGICAL DATA FOR

GREAT FALLS

LAT: 47.52 LONG: 111.30 ELEV: 1012(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.4	-3.0	-.8	6.3	11.8	16.0	20.7	19.7	14.1	9.1	1.4	-3.1
DAILY MAXIMUM	-1.5	2.2	4.7	12.5	18.3	22.3	28.7	27.7	21.1	15.2	6.3	1.5
DAILY MINIMUM	-11.3	-8.2	-6.3	.2	5.3	9.7	12.7	11.7	7.0	2.8	-3.5	-7.7
EXTREME MAXIMUM	16.1	17.8	22.2	28.3	32.2	36.1	40.6	41.1	36.7	29.4	22.2	16.1
EXTREME MINIMUM	-38.3	-30.0	-28.3	-15.0	-7.2	.0	4.4	2.8	-5.0	-19.4	-26.1	-41.7
HEATING DEGREE DAYS(18C)	766	597	594	360	203	90	10	23	144	291	506	663

CLIMATOLOGICAL DATA FOR

GREAT FALLS

LAT: 47.52 LONG: 111.30 ELEV: 3330(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	20.5	26.6	30.5	43.4	53.3	60.8	69.3	67.4	57.3	48.3	34.6	26.5
DAILY MAXIMUM	29.3	35.9	40.4	54.5	65.0	72.1	83.7	81.8	70.0	59.4	43.4	34.7
DAILY MINIMUM	11.6	17.2	20.6	32.3	41.5	49.5	54.9	53.0	44.6	37.1	25.7	18.2
EXTREME MAXIMUM	61.0	64.0	72.0	83.0	90.0	97.0	105.0	106.0	98.0	85.0	72.0	61.0
EXTREME MINIMUM	-37.0	-22.0	-19.0	5.0	19.0	32.0	40.0	37.0	23.0	-3.0	-15.0	-43.0
HEATING DEGREE DAYS(65F)	1380	1075	1070	648	367	162	18	42	260	524	912	1194

CLIMATOLOGICAL DATA FOR

HAMILTON

LAT: 46.25 LONG: 114.15 ELEV: 1094(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-4.0	-.4	2.3	7.6	11.9	15.4	19.7	18.6	13.7	8.1	1.6	-2.3
DAILY MAXIMUM	1.3	4.1	9.2	15.6	20.2	23.9	29.6	28.4	22.3	15.6	7.6	2.6
DAILY MINIMUM	-9.1	-7.1	-3.2	.7	4.3	7.6	10.4	9.3	5.4	.9	-3.8	-7.2
EXTREME MAXIMUM	16.7	21.7	23.3	32.2	38.9	37.8	39.4	38.9	36.7	32.2	22.2	18.9
EXTREME MINIMUM	-37.8	-39.4	-25.6	-17.2	-7.8	-1.7	.6	.0	-7.8	-18.3	-31.1	-34.4
HEATING DEGREE DAYS(18C)	692	525	496	321	201	95	15	36	148	318	503	638

CLIMATOLOGICAL DATA FOR

HAMILTON

LAT: 46.25 LONG: 114.15 ELEV: 3600(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	24.8	31.2	36.2	45.7	53.5	59.8	67.5	65.5	56.7	46.5	34.8	27.9
DAILY MAXIMUM	34.4	39.3	48.6	60.0	68.4	75.1	85.2	83.1	72.2	60.0	45.6	36.6
DAILY MINIMUM	15.7	19.2	26.2	33.2	39.7	45.7	50.8	48.8	41.7	33.6	25.2	19.1
EXTREME MAXIMUM	62.0	71.0	74.0	90.0	102.0	100.0	103.0	102.0	98.0	90.0	72.0	66.0
EXTREME MINIMUM	-36.0	-39.0	-14.0	1.0	18.0	29.0	33.0	32.0	18.0	-1.0	-24.0	-30.0
HEATING DEGREE DAYS(65F)	1246	946	893	579	362	171	27	66	267	574	906	1150

CLIMATOLOGICAL DATA FOR

HARLOWTON

LAT: 46.43 LONG: 109.83 ELEV: 1266(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.7	-3.6	-1.0	5.6	10.7	14.2	18.9	17.6	12.5	7.8	.4	-2.9
DAILY MAXIMUM	.9	3.3	6.3	13.6	19.1	22.3	28.5	27.7	21.9	16.4	7.6	3.5
DAILY MINIMUM	-12.3	-10.6	-8.3	-2.4	2.3	6.1	9.2	7.4	3.1	-.7	-6.7	-9.4
EXTREME MAXIMUM	17.2	23.3	24.4	30.6	33.9	35.0	38.9	38.3	36.1	32.8	25.6	20.6
EXTREME MINIMUM	-38.9	-39.4	-34.4	-22.2	-15.6	-4.4	.6	-1.7	-12.2	-15.0	-33.9	-39.4
HEATING DEGREE DAYS(18C)	745	601	604	394	235	115	25	45	177	311	533	658

CLIMATOLOGICAL DATA FOR

HARLOWTON

LAT: 46.43 LONG: 109.83 ELEV: 4167(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	21.7	25.5	30.2	42.1	51.3	57.6	66.0	63.6	54.5	46.1	32.8	26.7
DAILY MAXIMUM	33.6	38.0	43.4	56.5	66.4	72.2	83.3	81.8	71.4	61.5	45.6	38.3
DAILY MINIMUM	9.8	12.9	17.0	27.7	36.2	43.0	48.6	45.3	37.5	30.7	20.0	15.0
EXTREME MAXIMUM	63.0	74.0	76.0	87.0	93.0	95.0	102.0	101.0	97.0	91.0	78.0	69.0
EXTREME MINIMUM	-38.0	-39.0	-30.0	-8.0	4.0	24.0	33.0	29.0	10.0	5.0	-29.0	-39.0
HEATING DEGREE DAYS(65F)	1342	1083	1088	710	424	207	46	82	319	561	961	1186

CLIMATOLOGICAL DATA FOR

HAVRE

LAT: 48.57 LONG: 109.67 ELEV: 755(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-8.8	-7.3	-.9	7.3	13.2	17.2	21.8	20.0	13.9	8.2	-.6	-6.4
DAILY MAXIMUM	-3.2	-1.3	5.0	14.2	20.4	24.0	29.9	28.3	21.7	15.4	5.3	-.9
DAILY MINIMUM	-14.4	-13.3	-6.9	.3	5.9	10.3	13.7	11.7	6.1	.9	-6.6	-12.1
EXTREME MAXIMUM	18.3	21.7	25.0	35.0	36.7	41.7	41.7	41.1	36.7	32.8	23.3	21.7
EXTREME MINIMUM	-49.4	-44.4	-35.6	-22.2	-10.0	-1.7	2.8	-2.8	-7.8	-21.7	-33.3	-37.8
HEATING DEGREE DAYS(18C)	840	717	597	331	173	69	11	21	150	313	568	768

CLIMATOLOGICAL DATA FOR

HAVRE

LAT: 48.57 LONG: 109.67 ELEV: 2486(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	16.2	18.9	30.3	45.1	55.7	62.9	71.3	68.0	57.0	46.8	30.9	20.4
DAILY MAXIMUM	26.3	29.6	41.0	57.6	68.8	75.2	85.9	82.9	71.0	59.8	41.5	30.4
DAILY MINIMUM	6.1	8.1	19.5	32.5	42.6	50.6	56.6	53.1	42.9	33.7	20.2	10.3
EXTREME MAXIMUM	65.0	71.0	77.0	95.0	98.0	107.0	107.0	106.0	98.0	91.0	74.0	71.0
EXTREME MINIMUM	-57.0	-48.0	-32.0	-8.0	14.0	29.0	37.0	27.0	18.0	-7.0	-28.0	-36.0
HEATING DEGREE DAYS(65F)	1513	1291	1076	597	313	125	20	38	270	564	1023	1383

CLIMATOLOGICAL DATA FOR

HELENA

LAT: 46.58 LONG: 112.03 ELEV: 1253(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-7.4	-4.9	-.3	6.3	11.6	15.3	20.2	19.0	13.3	7.6	-.2	-4.3
DAILY MAXIMUM	-1.8	.9	5.8	13.4	18.8	22.4	29.1	27.9	21.6	14.9	5.8	1.2
DAILY MINIMUM	-13.1	-10.7	-6.6	-.8	4.4	8.1	11.3	10.1	5.1	.2	-6.2	-9.9
EXTREME MAXIMUM	10.0	15.6	21.1	24.4	30.0	31.1	35.0	35.0	32.8	29.4	19.4	15.0
EXTREME MINIMUM	-21.7	-23.9	-26.7	-11.1	-2.8	2.2	5.6	4.4	-7.2	-6.1	-19.4	-38.9
HEATING DEGREE DAYS(18C)	798	650	578	361	211	108	17	32	163	333	556	702

CLIMATOLOGICAL DATA FOR

HELENA

LAT: 46.58 LONG: 112.03 ELEV: 4124(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	18.6	23.2	31.4	43.3	52.9	59.5	68.4	66.2	56.0	45.6	31.6	24.2
DAILY MAXIMUM	28.8	33.7	42.5	56.1	65.8	72.3	84.4	82.2	70.8	58.8	42.4	34.2
DAILY MINIMUM	8.4	12.7	20.2	30.5	39.9	46.6	52.3	50.1	41.2	32.3	20.8	14.2
EXTREME MAXIMUM	50.0	60.0	70.0	76.0	86.0	88.0	95.0	95.0	91.0	85.0	67.0	59.0
EXTREME MINIMUM	-7.0	-11.0	-16.0	12.0	27.0	36.0	42.0	40.0	19.0	21.0	-3.0	-38.0
HEATING DEGREE DAYS(65F)	1438	1170	1042	651	381	195	31	59	294	601	1002	1265

CLIMATOLOGICAL DATA FOR

JORDAN

LAT: 47.32 LONG: 106.90 ELEV: 851(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-9.5	-5.8	-1.3	6.9	12.8	17.5	22.3	21.2	14.6	8.5	-.1	-6.0
DAILY MAXIMUM	-2.2	-.2	6.2	15.0	21.1	25.9	32.4	30.9	24.4	17.0	7.1	1.3
DAILY MINIMUM	-16.3	-15.1	-8.4	-1.3	4.4	9.3	12.9	11.2	5.1	-.9	-7.8	-12.9
EXTREME MAXIMUM	16.7	22.2	27.2	34.4	38.9	43.9	44.4	43.3	41.7	33.9	24.4	21.7
EXTREME MINIMUM	-46.1	-50.0	-37.2	-25.0	-12.2	-1.7	-.6	.0	-7.8	-25.6	-35.0	-39.4
HEATING DEGREE DAYS(18C)	862	675	609	341	175	70	7	12	133	305	551	754

CLIMATOLOGICAL DATA FOR

JORDAN

LAT: 47.32 LONG: 106.90 ELEV: 2800(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	14.9	21.6	29.6	44.5	55.1	63.5	72.1	70.1	58.2	47.3	31.9	21.2
DAILY MAXIMUM	28.1	31.7	43.2	59.0	70.0	78.6	90.3	87.7	75.9	62.6	44.8	34.4
DAILY MINIMUM	2.7	4.8	16.8	29.6	40.0	48.8	55.3	52.1	41.1	30.3	17.9	8.7
EXTREME MAXIMUM	62.0	72.0	81.0	94.0	102.0	111.0	112.0	110.0	107.0	93.0	76.0	71.0
EXTREME MINIMUM	-51.0	-58.0	-35.0	-13.0	10.0	29.0	31.0	32.0	18.0	-14.0	-31.0	-39.0
HEATING DEGREE DAYS(65F)	1553	1215	1097	615	316	127	14	22	240	549	993	1358

CLIMATOLOGICAL DATA FOR

KALISPELL

LAT: 48.22 LONG: 114.27 ELEV: 899(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.5	-3.9	.9	6.5	11.3	14.7	18.9	17.8	12.5	6.9	.0	-4.1
DAILY MAXIMUM	-2.2	1.2	6.2	12.9	18.3	21.9	27.8	26.9	20.5	13.2	3.9	-.4
DAILY MINIMUM	-10.8	-9.0	-4.4	.1	4.3	7.4	9.9	8.6	4.4	.5	-3.9	-7.7
EXTREME MAXIMUM	8.3	11.7	16.1	22.8	30.6	33.9	40.0	40.6	32.2	26.1	17.8	8.9
EXTREME MINIMUM	-30.6	-30.0	-33.9	-6.1	-2.2	-.6	2.2	2.8	-5.0	-7.8	-33.3	-25.6
HEATING DEGREE DAYS(18C)	770	622	538	355	217	119	26	46	181	355	550	693

CLIMATOLOGICAL DATA FOR

KALISPELL

LAT: 48.22 LONG: 114.27 ELEV: 2959(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	20.3	25.0	33.7	43.7	52.4	58.4	66.0	64.0	54.5	44.4	32.0	24.7
DAILY MAXIMUM	28.0	34.1	43.2	55.2	65.0	71.4	82.1	80.5	68.9	55.8	39.1	31.2
DAILY MINIMUM	12.6	15.8	24.1	32.2	39.8	45.4	49.9	47.4	40.0	32.9	24.9	18.2
EXTREME MAXIMUM	47.0	53.0	61.0	73.0	87.0	93.0	104.0	105.0	90.0	79.0	64.0	48.0
EXTREME MINIMUM	-23.0	-22.0	-29.0	21.0	28.0	31.0	36.0	37.0	23.0	18.0	-28.0	-14.0
HEATING DEGREE DAYS(65F)	1386	1120	970	639	391	215	47	83	326	639	990	1249

CLIMATOLOGICAL DATA FOR

LEWISTOWN

LAT: 47.07 LONG: 109.42 ELEV: 1203(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-6.9	-5.3	-1.9	4.9	10.3	14.1	18.9	18.0	12.7	7.8	.1	-3.6
DAILY MAXIMUM	-.6	1.3	4.3	11.9	17.7	21.3	27.7	26.9	20.9	15.4	6.6	2.8
DAILY MINIMUM	-13.2	-11.9	-8.1	-2.2	2.9	6.8	10.1	9.1	4.5	.2	-6.4	-9.9
EXTREME MAXIMUM	18.9	17.8	23.3	31.7	33.3	37.2	37.8	39.4	35.6	31.7	25.0	23.3
EXTREME MINIMUM	-36.7	-41.1	-33.3	-27.2	-11.7	-2.2	.6	.0	-6.7	-23.3	-33.9	-35.6
HEATING DEGREE DAYS(18C)	776	635	638	422	253	125	36	46	178	322	546	677

CLIMATOLOGICAL DATA FOR

LEWISTOWN

LAT: 47.07 LONG: 109.42 ELEV: 3960(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	19.6	22.5	28.6	40.8	50.5	57.3	66.1	64.4	54.9	46.1	32.2	25.6
DAILY MAXIMUM	31.0	34.4	39.8	53.5	63.8	70.4	81.9	80.4	69.6	59.8	43.8	37.0
DAILY MINIMUM	8.2	10.5	17.4	28.0	37.2	44.2	50.2	48.3	40.1	32.3	20.5	14.2
EXTREME MAXIMUM	66.0	64.0	74.0	89.0	92.0	99.0	100.0	103.0	96.0	89.0	77.0	74.0
EXTREME MINIMUM	-34.0	-42.0	-28.0	-17.0	11.0	28.0	33.0	32.0	20.0	-10.0	-29.0	-32.0
HEATING DEGREE DAYS(65F)	1397	1143	1149	760	456	225	66	84	322	581	984	1219

CLIMATOLOGICAL DATA FOR

LIBBY

LAT: 48.40 LONG: 115.58 ELEV: 624(M)

*** DEGREES CELSIUS ***

TEMPERATURE AVERAGES BY MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.6	-2.2	2.4	7.7	12.4	15.8	19.7	18.5	13.9	7.9	.3	-2.9
DAILY MAXIMUM	-.7	3.8	9.7	16.8	22.3	25.7	32.1	30.8	24.5	15.2	4.6	.7
DAILY MINIMUM	-10.5	-8.3	-4.9	-1.4	2.6	5.8	7.3	6.1	3.3	.7	-4.1	-6.5
EXTREME MAXIMUM	13.3	17.2	23.9	31.7	38.9	38.9	42.2	42.8	38.9	31.7	19.4	13.9
EXTREME MINIMUM	-38.9	-38.3	-28.9	-20.6	-11.1	-4.4	-1.1	-2.2	-8.9	-21.7	-32.2	-31.1
HEATING DEGREE DAYS(18C)	716	550	510	331	189	88	26	35	140	340	547	655

CLIMATOLOGICAL DATA FOR

LIBBY

LAT: 48.40 LONG: 115.58 ELEV: 2053(FT)

*** DEGREES FAHRENHEIT ***

TEMPERATURE AVERAGES BY MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	22.0	28.0	36.4	45.8	54.4	60.4	67.5	65.3	57.0	46.3	32.5	26.8
DAILY MAXIMUM	30.8	38.9	49.5	62.2	72.1	78.2	89.7	87.5	76.1	59.4	40.2	33.3
DAILY MINIMUM	13.1	17.1	23.2	29.4	36.7	42.5	45.2	43.0	37.9	33.2	24.7	20.3
EXTREME MAXIMUM	56.0	63.0	75.0	89.0	102.0	102.0	108.0	109.0	102.0	89.0	67.0	57.0
EXTREME MINIMUM	-38.0	-37.0	-20.0	-5.0	12.0	24.0	30.0	28.0	16.0	-7.0	-26.0	-24.0
HEATING DEGREE DAYS(65F)	1290	991	919	596	341	159	48	64	252	613	985	1179

CLIMATOLOGICAL DATA FOR

LIVINGSTON

LAT: 45.65 LONG: 110.57 ELEV: 1364(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-4.1	-1.9	.8	6.4	11.3	15.1	20.1	19.1	14.1	9.2	1.9	-1.1
DAILY MAXIMUM	1.3	3.8	6.9	13.6	18.9	22.8	29.4	28.6	22.5	16.4	7.3	4.0
DAILY MINIMUM	-9.4	-7.7	-5.4	-.7	3.7	7.4	10.7	9.7	5.7	1.9	-3.6	-6.0
EXTREME MAXIMUM	15.0	19.4	22.2	30.6	33.9	40.6	38.9	38.3	36.7	29.4	22.8	20.0
EXTREME MINIMUM	-36.7	-42.8	-29.4	-23.3	-11.1	-2.2	1.7	.0	-6.7	-22.2	-32.8	-32.2
HEATING DEGREE DAYS(18C)	668	537	541	361	211	91	20	30	134	271	484	584

CLIMATOLOGICAL DATA FOR

LIVINGSTON

LAT: 45.65 LONG: 110.57 ELEV: 4490(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	24.7	28.5	33.4	43.6	52.4	59.2	68.2	66.4	57.4	48.6	35.4	30.1
DAILY MAXIMUM	34.3	38.8	44.5	56.4	66.0	73.0	85.0	83.4	72.5	61.6	45.2	39.2
DAILY MINIMUM	15.1	18.2	22.2	30.7	38.7	45.4	51.3	49.4	42.2	35.5	25.5	21.2
EXTREME MAXIMUM	59.0	67.0	72.0	87.0	93.0	105.0	102.0	101.0	98.0	85.0	73.0	68.0
EXTREME MINIMUM	-34.0	-45.0	-21.0	-10.0	12.0	28.0	35.0	32.0	20.0	-8.0	-27.0	-26.0
HEATING DEGREE DAYS(65F)	1204	968	974	650	380	165	36	55	242	488	872	1052

CLIMATOLOGICAL DATA FOR

MILESCITY

LAT: 46.42 LONG: 105.82 ELEV: 718(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-8.6	-6.5	-.6	7.6	14.1	18.7	24.1	22.6	16.1	9.4	.3	-4.9
DAILY MAXIMUM	-2.6	-.1	5.7	14.8	21.4	25.8	32.3	30.8	24.0	16.9	6.4	.9
DAILY MINIMUM	-14.7	-12.9	-7.0	.4	6.7	11.4	15.8	14.3	8.2	1.9	-5.7	-10.7
EXTREME MAXIMUM	16.7	18.9	28.3	32.8	37.2	40.0	42.8	43.3	40.6	33.9	23.9	20.6
EXTREME MINIMUM	-38.3	-38.3	-32.8	-13.9	-9.4	.0	5.0	1.7	-6.7	-12.8	-30.6	-35.0
HEATING DEGREE DAYS(18C)	835	695	587	321	153	55	3	3	96	278	540	720

CLIMATOLOGICAL DATA FOR

MILESCITY

LAT: 46.42 LONG: 105.82 ELEV: 2364(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	16.5	20.3	30.9	45.7	57.4	65.6	75.3	72.6	61.0	49.0	32.6	23.2
DAILY MAXIMUM	27.4	31.8	42.3	58.6	70.6	78.5	90.2	87.5	75.2	62.4	43.5	33.6
DAILY MINIMUM	5.6	8.7	19.4	32.8	44.1	52.6	60.4	57.7	46.7	35.5	21.7	12.8
EXTREME MAXIMUM	62.0	66.0	83.0	91.0	99.0	104.0	109.0	110.0	105.0	93.0	75.0	69.0
EXTREME MINIMUM	-37.0	-37.0	-27.0	7.0	15.0	32.0	41.0	35.0	20.0	9.0	-23.0	-31.0
HEATING DEGREE DAYS(65F)	1504	1252	1057	579	276	99	6	6	174	502	972	1296

CLIMATOLOGICAL DATA FOR

MISSOULA

LAT: 46.87 LONG: 114.00 ELEV: 979(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-7.0	-3.5	1.5	7.1	12.0	15.7	20.2	18.9	13.2	7.2	-.1	-4.7
DAILY MAXIMUM	-1.9	2.1	7.6	14.4	19.9	23.8	30.2	28.8	21.9	14.4	4.9	-.2
DAILY MINIMUM	-12.2	-9.1	-4.6	-.3	4.1	7.5	10.2	9.1	4.5	-.2	-5.1	-9.2
EXTREME MAXIMUM	8.9	13.3	21.1	25.6	30.0	35.6	40.6	40.6	30.0	26.1	14.4	7.8
EXTREME MINIMUM	-25.6	-7.8	-22.2	-6.7	-5.6	-.6	2.2	.0	-4.4	-8.3	-16.7•	-26.1
HEATING DEGREE DAYS(18C)	785	611	521	338	202	97	12	31	162	346	551	712

CLIMATOLOGICAL DATA FOR

MISSOULA

LAT: 46.87 LONG: 114.00 ELEV: 3223(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	19.4	25.7	34.7	44.7	53.6	60.2	68.4	66.1	55.8	44.9	31.9	23.6
DAILY MAXIMUM	28.6	35.7	45.6	57.9	67.8	74.8	86.3	83.8	71.4	58.0	40.9	31.6
DAILY MINIMUM	10.1	15.6	23.7	31.4	39.4	45.5	50.4	48.3	40.1	31.7	22.9	15.5
EXTREME MAXIMUM	48.0	56.0	70.0	78.0	86.0	96.0	105.0	105.0	86.0	79.0	58.0	46.0
EXTREME MINIMUM	-14.0	18.0	-8.0	20.0	22.0	31.0	36.0	32.0	24.0	17.0	2.0	-15.0
HEATING DEGREE DAYS(65F)	1414	1100	939	609	365	176	22	57	292	623	993	1283

CLIMATOLOGICAL DATA FOR

PLENTYWOOD

LAT: 48.78 LONG: 104.57 ELEV: 615(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-13.4	-10.2	-4.3	5.6	12.3	16.9	20.8	20.1	13.7	7.7	-2.2	-9.4
DAILY MAXIMUM	-7.3	-4.7	1.9	13.0	20.1	24.3	28.8	28.4	21.8	14.2	3.4	-3.2
DAILY MINIMUM	-20.4	-18.1	-10.9	-1.9	4.3	9.4	11.8	10.4	4.9	-1.3	-9.3	-15.4
EXTREME MAXIMUM	12.2	20.0	25.0	33.3	39.4	40.0	47.2	41.7	38.3	31.7	23.3	20.0
EXTREME MINIMUM	-46.1	-50.0	-38.9	-21.1	-11.7	-5.6	-1.1	-1.1	-12.8	-21.7	-35.0	-41.1
HEATING DEGREE DAYS(18C)	983	799	702	381	191	75	11	20	152	330	616	859

CLIMATOLOGICAL DATA FOR

PLENTYWOOD

LAT: 48.78 LONG: 104.57 ELEV: 2024(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	7.9	13.6	24.2	42.1	54.1	62.5	69.5	68.1	56.7	45.8	28.0	15.1
DAILY MAXIMUM	18.9	23.6	35.4	55.4	68.2	75.7	83.9	83.2	71.2	57.6	38.1	26.3
DAILY MINIMUM	-4.7	-.6	12.3	28.5	39.7	48.9	53.3	50.8	40.9	29.7	15.2	4.3
EXTREME MAXIMUM	54.0	68.0	77.0	92.0	103.0	104.0	117.0	107.0	101.0	89.0	74.0	68.0
EXTREME MINIMUM	-51.0	-58.0	-38.0	-6.0	11.0	22.0	30.0	30.0	9.0	-7.0	-31.0	-42.0
HEATING DEGREE DAYS(65F)	1770	1439	1265	687	344	135	21	37	275	595	1110	1547

CLIMATOLOGICAL DATA FOR

POLSON

LAT: 47.68 LONG: 114.17 ELEV: 896(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-3.9	-2.3	1.7	7.1	11.7	15.4	19.7	18.7	13.8	7.9	1.4	-1.3
DAILY MAXIMUM	-.6	1.8	6.7	13.2	18.4	22.3	27.9	26.8	20.7	13.3	5.3	1.9
DAILY MINIMUM	-7.4	-6.4	-3.2	1.1	4.9	8.6	11.3	10.6	6.8	2.6	-2.5	-4.4
EXTREME MAXIMUM	14.4	18.3	22.2	25.0	31.7	33.9	40.0	38.3	32.8	27.8	18.3	16.7
EXTREME MINIMUM	-34.4	-32.8	-23.3	-18.3	-8.3	-1.1	2.8	.6	-3.9	-17.2	-29.4	-25.6
HEATING DEGREE DAYS(18C)	667	553	530	346	216	100	31	31	146	338	518	608

CLIMATOLOGICAL DATA FOR

POLSON

LAT: 47.68 LONG: 114.17 ELEV: 2949(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	24.9	27.9	35.1	44.8	53.0	59.8	67.4	65.7	56.8	46.3	34.5	29.7
DAILY MAXIMUM	31.0	35.3	44.0	55.7	65.1	72.1	82.3	80.3	69.3	55.9	41.5	35.4
DAILY MINIMUM	18.7	20.4	26.2	33.9	40.8	47.4	52.4	51.1	44.2	36.6	27.5	24.0
EXTREME MAXIMUM	58.0	65.0	72.0	77.0	89.0	93.0	104.0	101.0	91.0	82.0	65.0	62.0
EXTREME MINIMUM	-30.0	-27.0	-10.0	-1.0	17.0	30.0	37.0	33.0	25.0	1.0	-21.0	-14.0
HEATING DEGREE DAYS(65F)	1201	996	954	623	389	180	57	57	264	609	934	1096

CLIMATOLOGICAL DATA FOR

RED LODGE

LAT: 45.18 LONG: 109.25 ELEV: 1686(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-5.3	-3.6	-1.9	4.2	9.3	13.2	17.9	17.2	11.8	7.3	.2	-3.1
DAILY MAXIMUM	.7	2.5	4.4	10.7	16.0	19.9	25.9	25.2	19.0	13.9	6.1	2.4
DAILY MINIMUM	-11.4	-9.7	-8.3	-2.3	2.7	6.3	9.9	9.3	4.6	.6	-5.6	-8.7
EXTREME MAXIMUM	21.1	17.2	21.1	25.6	29.4	33.3	36.7	35.0	32.2	28.3	22.8	17.2
EXTREME MINIMUM	-37.8	-31.7	-34.4	-23.3	-13.9	-3.9	-1.1	-2.2	-12.8	-13.9	-31.7	-35.0
HEATING DEGREE DAYS(18C)	717	594	610	429	262	142	38	54	185	329	534	652

CLIMATOLOGICAL DATA FOR

RED LODGE

LAT: 45.18 LONG: 109.25 ELEV: 5548(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	22.4	25.5	28.6	39.6	48.8	55.7	64.3	63.0	53.3	45.1	32.4	26.4
DAILY MAXIMUM	33.2	36.5	40.0	51.2	60.8	67.9	78.6	77.3	66.2	57.1	42.9	36.4
DAILY MINIMUM	11.5	14.5	17.1	27.9	36.8	43.4	49.9	48.7	40.3	33.1	21.9	16.3
EXTREME MAXIMUM	70.0	63.0	70.0	78.0	85.0	92.0	98.0	95.0	90.0	83.0	73.0	63.0
EXTREME MINIMUM	-36.0	-25.0	-30.0	-10.0	7.0	25.0	30.0	28.0	9.0	7.0	-25.0	-31.0
HEATING DEGREE DAYS(65F)	1291	1070	1098	773	473	256	70	98	333	593	962	1174

CLIMATOLOGICAL DATA FOR

SIDNEY

LAT: 47.70 LONG: 104.17 ELEV: 586(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-11.1	-7.7	-2.3	6.7	12.9	17.5	21.6	20.7	14.3	8.4	-.8	-7.1
DAILY MAXIMUM												
DAILY MINIMUM												
EXTREME MAXIMUM	DATA NOT AVAILABLE											
EXTREME MINIMUM												
HEATING DEGREE DAYS(18C)	911	727	638	350	175	65	9	18	140	306	575	788

CLIMATOLOGICAL DATA FOR

SIDNEY

LAT: 47.70 LONG: 104.17 ELEV: 1928(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	12.1	18.2	27.9	44.0	55.2	63.5	70.8	69.2	57.7	47.2	30.5	19.2
DAILY MAXIMUM												
DAILY MINIMUM												
EXTREME MAXIMUM	DATA NOT AVAILABLE											
EXTREME MINIMUM												
HEATING DEGREE DAYS(65F)	1640	1310	1150	630	315	118	17	33	253	552	1035	1420

CLIMATOLOGICAL DATA FOR

THOMPSON FALLS

LAT: 47.58 LONG: 115.33 ELEV: 748(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-3.1	.6	3.3	8.3	12.8	16.2	20.3	19.6	15.1	8.9	2.4	-1.1
DAILY MAXIMUM	1.2	5.7	9.9	16.3	21.5	24.8	31.0	30.2	24.6	16.2	6.8	2.4
DAILY MINIMUM	-7.3	-4.7	-3.3	.3	4.1	7.6	9.6	8.9	5.6	1.7	-2.1	-4.6
EXTREME MAXIMUM	13.3	17.8	25.6	32.2	36.1	37.8	42.8	41.7	41.1	31.7	18.3	14.4
EXTREME MINIMUM	-37.8	-34.4	-23.3	-8.3	-6.7	-1.1	1.7	.0	-4.4	-7.8	-25.0	-31.7
HEATING DEGREE DAYS(18C)	646	495	470	308	172	74	17	25	109	288	480	601

CLIMATOLOGICAL DATA FOR

THOMPSON FALLS

LAT: 47.58 LONG: 115.33 ELEV: 2463(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	26.5	33.0	38.0	46.9	55.0	61.2	68.5	67.2	59.2	48.1	36.3	30.1
DAILY MAXIMUM	34.1	42.3	49.9	61.3	70.7	76.6	87.8	86.3	76.2	61.2	44.3	36.4
DAILY MINIMUM	18.8	23.6	26.0	32.5	39.3	45.7	49.2	48.1	42.1	35.0	28.3	23.7
EXTREME MAXIMUM	56.0	64.0	78.0	90.0	97.0	100.0	109.0	107.0	106.0	89.0	65.0	58.0
EXTREME MINIMUM	-36.0	-30.0	-10.0	17.0	20.0	30.0	35.0	32.0	24.0	18.0	-13.0	-25.0
HEATING DEGREE DAYS(65F)	1164	891	847	556	311	134	32	46	197	519	864	1083

CLIMATOLOGICAL DATA FOR

WEST YELLOWSTONE

LAT: 44.92 LONG: 111.07 ELEV: 2026(M)

TEMPERATURE AVERAGES BY MONTH *** DEGREES CELSIUS ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	-10.6	-8.4	-5.3	1.1	6.7	10.8	15.3	14.1	8.9	3.2	-5.2	-9.9
DAILY MAXIMUM	-4.3	-.4	3.4	8.9	15.2	19.8	26.6	25.2	19.1	11.8	1.6	-3.3
DAILY MINIMUM	-16.9	-16.5	-14.1	-6.8	-1.8	1.8	4.1	2.9	-1.2	-5.4	-11.9	-16.6
EXTREME MAXIMUM	7.8	13.3	16.1	22.2	28.3	32.8	35.0	35.6	32.8	26.1	17.8	12.2
EXTREME MINIMUM	-51.1	-46.7	-41.7	-27.2	-17.8	-7.2	-6.7	-7.8	-11.7	-20.0	-37.8	-46.7
HEATING DEGREE DAYS(18C)	910	756	744	526	353	217	83	127	272	464	702	884

CLIMATOLOGICAL DATA FOR

WEST YELLOWSTONE

LAT: 44.92 LONG: 111.07 ELEV: 6665(FT)

TEMPERATURE AVERAGES BY MONTH *** DEGREES FAHRENHEIT ***

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY AVERAGE	12.9	16.8	22.4	33.9	44.1	51.5	59.6	57.3	48.1	37.8	22.7	14.1
DAILY MAXIMUM	24.2	31.2	38.1	48.0	59.3	67.7	79.9	77.3	66.3	53.3	34.9	26.1
DAILY MINIMUM	1.5	2.3	6.6	19.8	28.8	35.2	39.3	37.2	29.8	22.2	10.5	2.1
EXTREME MAXIMUM	46.0	56.0	61.0	72.0	83.0	91.0	95.0	96.0	91.0	79.0	64.0	54.0
EXTREME MINIMUM	-60.0	-52.0	-43.0	-17.0	.0	19.0	20.0	18.0	11.0	-4.0	-36.0	-52.0
HEATING DEGREE DAYS(65F)	1638	1361	1340	947	636	392	151	230	491	836	1265	1592

APPENDIX I: ACCURACY OF SIMM SOLAR RADIATION MEASUREMENTS

1.0 INSTRUMENTATION

The solar radiation measurements were made using a silicon cell-based transducer fabricated by Fowlkes Engineering and a Rustrak Model 288, 0-1 ma, strip chart recorder. The silicon cell is 2 cm square and is attached flush to the center of a flat aluminum heat sink approximately 8 cm square. An aluminum reflective mask, 8 cm square and 0.5 mm thick, having a 1.9 cm square hole is centered over the silicon cell. A piece of double strength window glass, 8 cm square and 3 mm thick, covers the assembly. The assembly is sealed along the perimeter with clear silicone rubber caulking to prevent moisture from entering. The purpose of the reflector and the heat sink is to stabilize the temperature of the silicon cell.

The output of the silicon cell is shunted with a wire wound resistor having a resistance of less than 1 Ω . The voltage drop across this resistor at normal incidence on a clear day is about 80 mv. The recorder has an input impedance of about 100 Ω and is consequently deflected to about 80% of full scale at solar noon on a clear day. To reduce the effect of lead resistance, two- conductor, #18 solid copper wire is used to connect the transducer to the recorder.

1.1 Initial Calibration

Each transducer-lead wire-recorder assembly is individually calibrated by comparison to a Kipp or Eppley pyranometer. The reference pyranometer and silicon cell transducer are mounted in the same plane. The plane of the transducers is adjusted approximately normal to the solar radiation on a clear day near solar noon. Several simultaneous readings of both instruments are averaged to establish the initial calibration factor. The reference pyranometer was manufactured by Kipp and was recalibrated at the NOAA Laboratories in Boulder, Colorado by Dr. Ed Flowers. One of the SIMM transducers was also calibrated at the NOAA Laboratories in 1978. Periodic comparisons with several other Eppley and Li-Cor pyranometers have shown agreement with the reference to within $\pm$ 5% or better.

2.0 SOURCES OF ERROR

2.1 Silicon Cell Characteristics

Silicon cell characteristics relating to solar flux measurement are well documented in the literature (see References) and several commercial silicon cell instruments are available. Briefly, the silicon cell characteristics causing departures from pyranometer readings are due to spectral response, temperature changes and cosine response. The spectral response will cause the silicon cell to read measurably higher on cloudy days and within 2 hours of sunrise or sunset. The instruments used in this program, for example, will be 0.015 kW/m^2 high under conditions of 80% beam attenuation due to clouds. The amplitude error in this condition is $\pm$ 6%. The effect of this spectral error on the monthly average, daily total energy density (the values tabulated in this Manual) is typically reduced to less than 3%. This reduced error is due to the relatively low energy density on cloudy days. Similarly, amplitude errors near sunrise and sunset have a small effect on daily total energy density: less than 2% on a clear day.

Temperature coefficients of about +0.001/°C are given in the literature for silicon cells used for flux measurements. All instruments used in this project were calibrated during the month of January. Summer operating temperatures would be about 35° C higher which, based on + 0.001/°C, would produce 3.5% higher amplitudes for a given radiant flux. It might be noted that some commercial pyranometers have a temperature sensitivity of about -0.001/°C.

2.2 Transducer Errors

The SIMM silicon cell transducer is covered by a glass plate potted in silicone sealant. Tilt calibration tests have shown that the output of the SIMM transducer falls off at large angles of incidence. This is due primarily to the glass cover plate and is normally termed cosine error.

The measured cosine response of the SIMM transducer was input into a computer simulation model to predict the effect of this error on the daily total insolation throughout the year. The following table shows the results of this computer model. Experimental data presented later in this report indicates that the summer errors are less than those predicted by the model.

CALCULATED EFFECT OF COSINE ERROR, %

MONTH	CLEAR DAY	AVERAGE DAY
DEC	-2	-2
JAN NOV	-3	-2
FEB OCT	-4	-3
MAR SEP	-4	-3
APR AUG	-6	-4
MAY JUL	-8	-5
JUN	-8	-5

2.3 Orientation Errors

The nominal plane of measurement is 60° up from horizontal and south facing. No thorough measurements are available to establish typical accuracy of the plane of the transducers at this time. The attachment bracket was fabricated to $\pm 1^{\circ}$ and many of the transducers used buildings oriented true south for mounting. A compass was used in some cases, corrected for the local magnetic deviation, to establish the azimuth.

The error due to misalignment varies as $\cos(\theta + \delta)$ where δ is the misalignment and θ is the angle between the radiation on a normal-to-the-transducer plane. At solar noon during the heating season this error would be a maximum of around 0.3% per degree of misalignment. This error will be assumed negligible until further data and analyses are available.

2.4 Recorder Errors

The published absolute accuracy of the strip chart recorders is 3%. This error is reduced significantly since the recorders are directly calibrated in conjunction with the transducers. The readability of the recorder during calibration, using a magnifier, is estimated at better than $\pm$ 1%.

The electrical circuit used is sensitive to changes in lead resistance. This factor has probably been the primary source of error in this measurement program. At a few stations extra lead wire was installed after calibration. Even more important have been resistance variations

due to improperly soldered lead wire connections. The gradually increasing contact resistance leads to a gradual reduction in sensitivity of the instrument. In a few cases this problem has been responsible for temporary errors of 10 and 20%.

2.5 Data Reduction Errors

Strip chart data is processed by tracing the curves on a digitizer platen connected to a microcomputer. The resolution of the platen is 0.1 mm and each curve is represented by 200 to 400 coordinates. The reading error due to resolution is, thus, less than 1%. The primary source of data reduction error is the repeatability of the curve tracing itself. On clear days, where the curve is a well defined line, the reproducibility averages 1%. On cloudy days the reproducibility can reach 5 to 20%. This is due to the fast response of the silicon cell which produces a very rough, jagged curve on some cloudy days (see cover of Manual for examples of curves).

During the last year, reproducibility tests have been run on over 800 data days (4% of our total data base). The reproducibility of the monthly average, daily total energy density averages better than $\pm$ 2%. These monthly values often reproduce within 1% due to the compensation of positive and negative errors when averaged.

3.0 DATA CORRECTION PROCEDURES

The Department of Energy has sponsored programs to compile and review historical solar insolation data for the purpose of providing a data base for the design of solar energy conversion devices. Expert review of the data pointed to a myriad of errors due to instrumentation, data collection and presentation. Programs were subsequently initiated to "rehabilitate" this data base.

A key part of the rehabiliatation consisted of reviewing approximately 190,000 solar radiation charts and extracting the radiation intensity at solar noon on clear days. A parallel effort consisted of computing predicted clear-day noon radiation using a variety of theoretical models and atmospheric data. The comparison of the theoretical and experimental clear-day data identified unreliable solar data (some

data being 20% in error). The comparison further helped provide correction factors which were applied to the experimental data to produce the "rehabilitated" solar data base. The rehabilitated data is believed to be accurate to within ± 5%. These data are now available in the form of tables and computer-readable tapes for 26 locations in the United States; Great Falls is among the rehabilitated stations.

Estimates of the solar radiation at an additional 222 locations were derived from atmospheric data and are included in the SOLMET data base. Eight of these locations are in Montana. The accuracy of this calculation method for Great Falls is ± 13% for daily values and ± 4% for monthly averages.

3.1 Data Correction Procedures for SIMM

The clear-day comparison procedure described above was also utilized in processing the data presented in this Manual. This comparison significantly reduces the probability of large errors in the solar radiation due to faulty instrumentation. We were fortunate to have the guidance of expert consultants in this crucial area.

Douglas V. Hoyt of NOAA in Boulder, Colorado was involved with the rehabilitation of the SOLMET data base using his theoretical model for the calculation of solar noon atmospheric transmission. He was able to provide us with theoretical clear-day values on a 60° tilted surface in Montana using his comprehensive atmospheric model. He also advised us as to the effect of altitude on our clear-day values and provided general guidance in assessing the accuracy of the data.

John Yellott has provided useful advice on the behavior of silicon cell-based instruments for measuring solar radiation since the inception of this measurement program. Prof. Yellott holds a patent on the temperature-compensated silicon cell radiometer. He also advised us concerning the use of the ASHRAE clear-day model for checking instruments for calibration drift.

3.2 Our Theoretical Clear-Day Model

For this report we used a theoretical clear-day model based on one

given in the ASHRAE Handbook of Fundamentals. Our model included an adjustment for altitude consisting of a clearness factor allowing + 1% per 1000 feet in elevation. The effect of ground reflection was included by assuming a reflectance of 0.5 (snow) for Nov. 15 to March 1 and a reflectance of 0.2 during the remainder of the year.

The results from Doug Hoyt's clear-day model and our modified ASHRAE clear-day models are shown in Figure 1(a) for Great Falls along with the experimental data. The two theoretical curves are within $\pm$ 2.5%. Most of the experimental data is also contained in this $\pm$ 2.5% error band.

Note that some experimental clear-day values in winter are as much as 5% above the theoretical values. Several stations showed a similar relative increase in clear-day values during winter. At this time we don't know if the experimental data or the theoretical model is responsible for this departure. The Great Falls experimental data was not corrected due to the close agreement with the theoretical values.

Figure 1(b) shows the clear-day comparison for Glendive. The discrepancy between the theoretical and experimental values suggested a uniform offset in the calibration factor of 4.5%. The data presented in the tables is the raw data multiplied by a factor of 1.045. The dashed curve in Figure 1(b) shows how this offset factor produces an improved fit between the experimental data and the clear-day model.

4.0 NATIONAL SOLAR DATA NETWORK COMPARISON

The Billings Shipping solar system in Billings, Montana was instrumented three years ago for performance monitoring as part of The National Solar Data Network (NSDN). Global insolation is measured here by an Eppley PSP pyranometer tilted at 50°. Daily totals and maximums are reported each month in "Environmental Data for Sites in the National Solar Data Network", DOE National Solar Data Program, Solar 10010-80.

During 1980 there were 337 days of simultaneous data from both the NSDN, Eppley PSP and the SIMM transducer at Billings High School. The NSDN 50° tilt data was converted to a 60° tilt using the ratio of ASHRAE clear day totals. This simplified method would tend to over-correct the NSDN data by a few percent in the summer. Since the correc-

tion itself averages only about ± 3%, the error introduced is not large.

A scatter plot of daily total insolation for SIMM vs. NSDN for 1980 is shown in Figure 2. For 337 common data days, the linear correlation coefficient was 0.990. There are about a dozen points that are scattered. These discrepancies probably occurred on days when snow or frost covered one transducer part of that day. Neither instrument is regularly cleaned or cleared of snow. The remaining scatter is primarily due to differences in spectral response, calibration error, cosine response and temperature coefficient (annual temperature extremes span over 70° C).

The daily totals for the month of November, 1980 are shown in Table 1. The daily average insolation for November for the SIMM instrument is 3.07% less than the NSDN instrument. This difference closely corresponds to the -3% error predicted for this month due to the low cosine response of the SIMM transducer.

The average daily totals for each instrument are shown for each month in 1980 in Table 2. The SIMM instrument is normally lower by a few percent, which is probably due to cosine error. (The December average is faulted because the SIMM instrument was not recording data during a week with several clear days.)

5.0 BOZEMAN SIDE BY SIDE COMPARISONS

Side by side comparisons were run for eight months during the winter of 1980 and spring of 1981 to compare (a) a Kipp pyranometer, (b) a Li-Cor 200S silicon cell radiometer, and (c) the SIMM silicon cell radiometer. All transducers were mounted at 0° azimuth and 60° tilt and connected to a microcomputer based data acquisition system (DAS). The DAS had a resolution of 12 bits, an accuracy of better than ± 0.5%; each transducer and the ambient air temperature were sampled once each second. These readings were averaged over 10 minute intervals and the average data stored on magnetic tape. This data base consists of 15×10^6 side by side readings of each transducer.

Table 3 shows a typical portion of this data base condensed into daily total insolation. The Kipp pyranometer was recalibrated at the NOAA facility in 1979 and this calibration factor was used. The factory calibration supplied for the Li-Cor was used and the SIMM transducer was calibrated to the Kipp on a clear day near solar noon

according to our standard procedure. No correction was made for ambient temperature, which varied between -18° C and +17° C during this period. The monthly totals of the Kipp and the Li-Cor agree to within ± 1% while the SIMM transducer is 3% below the Kipp. This lower reading agrees with the predictions of the cosine error model discussed previously.

The instantaneous readings of the three transducers during mid-day in clear weather were always within a ± 5% band and often were within ± 1%. The Kipp and the Li-Cor were typically within ± 0.01 $kW-m^{-2}$ for the entire day, while the SIMM transducer's output would typically be 0.05 $kW-m^{-2}$ low in early morning and late afternoon (the cosine error).

6.0 ACCURACY SUMMARY

The expected error in the monthly average data for any station has been summarized by assigning to each station a classification ranging from I to III. This error classification was based primarily on comparisons of theoretical and experimental clear-day values, before and after adjustment. Table 4 lists these comparisons.

Additional information from our instrument records and fault code files was also used to refine the classification. In 1978, Helena is Class I even though the adjusted error is 4.6, the highest of any Class I station. This scatter is due to a characteristic haze in Helena which effects the "clear-day" values. In 1978, Lewistown was rated Class III even though the adjusted error was only 2.3% (less than many Class I stations). Lewistown's rating was reduced due to persistent problems with unreliable connections and slipping chart paper which reduced the overall integrity of the data.

Based on our current clear-day model, we suggest the following overall error bands for monthly average data:

Class I stations	± 3%
Class II stations	± 5%
Class III stations	± 8%

All calculations to date indicate that if there is a significant discrepancy, the solar data in this Manual will be conservative; i.e. less than the true value. This error margin is due to the cosine response of the instruments and the clear day calibration method.

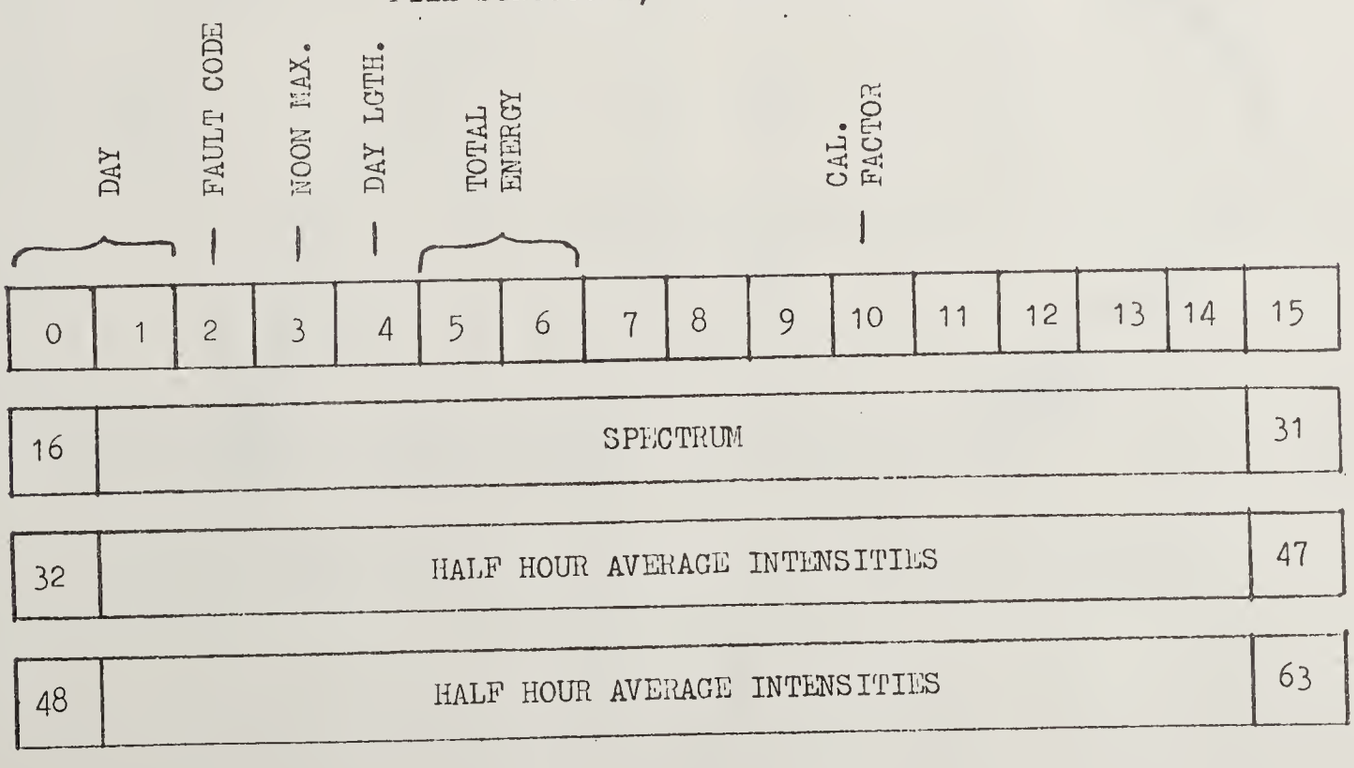
(A solar system designed using radiation data that is 10% low will produce about 5% more heat than expected.) The errors in the data in this Manual are probably less than the error band of most solar system design methods.

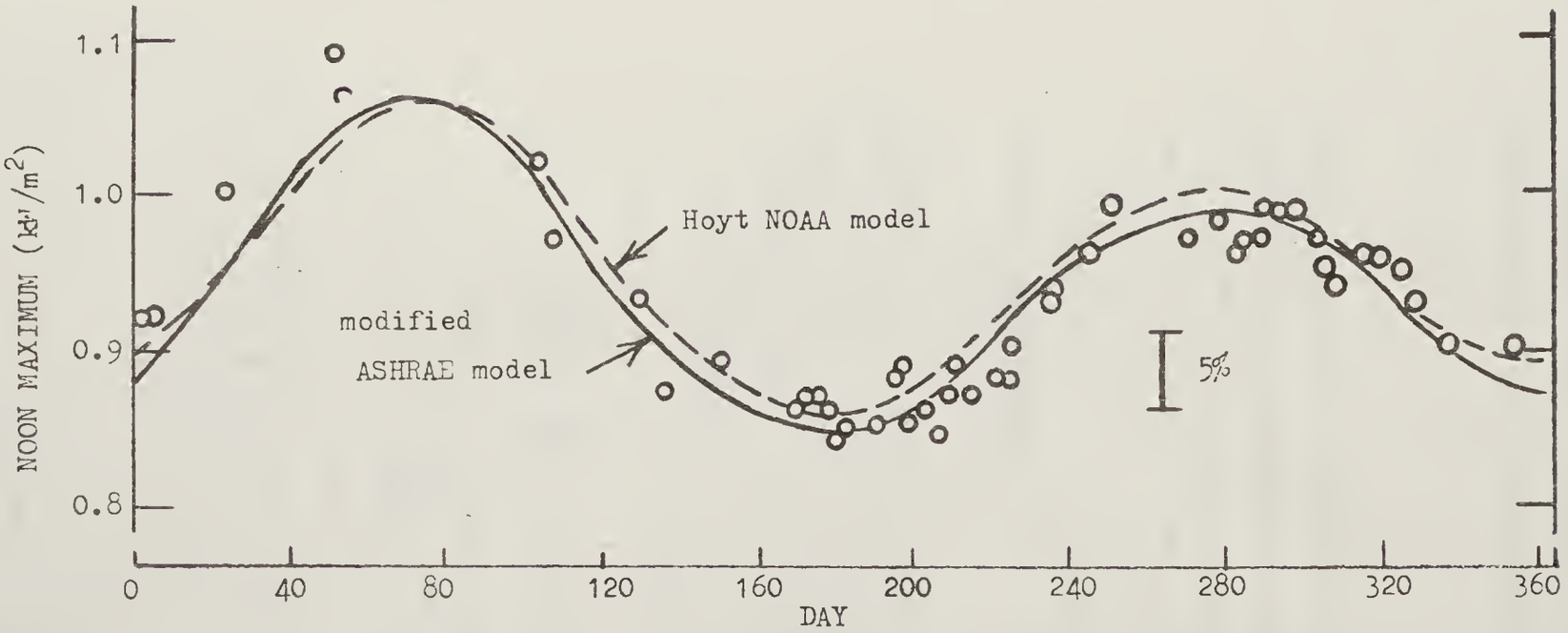
7.0 FILE STRUCTURE

The processed data from each day consists of day number, total energy density, day length, noon maximum intensity (if day was clear), intensity spectrum, half-hour average solar intensities, and a fault code (specifying lost or suspect data). The total energy is stored in 2 (8 bit) bytes and, thus, has a maximum resolution of 1 part in 512. All other non-integer quantities are rounded to integers and stored in a single byte in the file (maximum resolution 1 part in 256). The maximum loss of precision in this data due to rounding off is 0.5%.

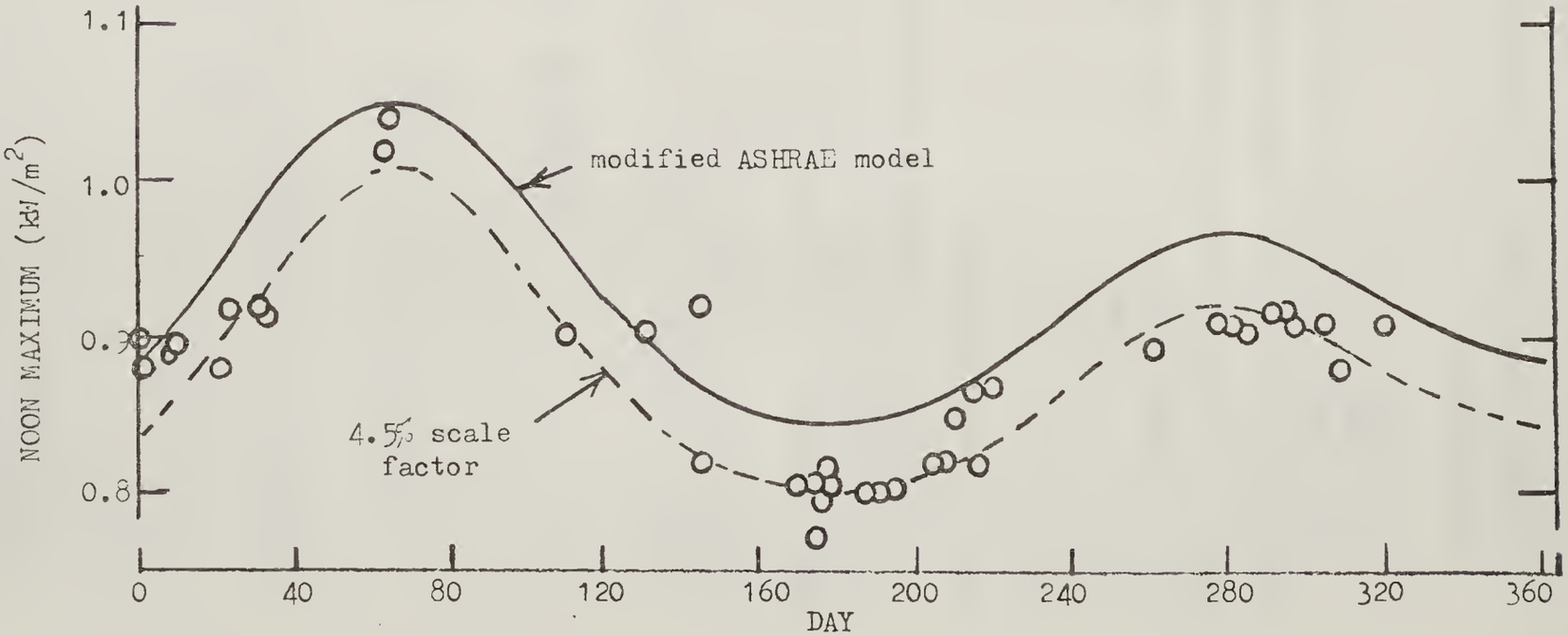
The data are stored on hard sectored, 5¼ inch magnetic diskettes using the North Star Disc Operating System (a popular microcomputer format). Each single-density diskette contains 3 station-years of solar data. These data have been used by Fowlkes Engineering as input to solar heating simulation models. Copies of these diskettes can be supplied at nominal cost for users wanting to implement their own simulation programs.

FILE STRUCTURE, 1 STATION - DATA - DAY





(a) Great Falls data for 1978 showing two clear-day models with data



(b) Glendive data for 1978 illustrating use of scale factor

Figure 1. Comparison of clear[illegible] experimental and theoretical values

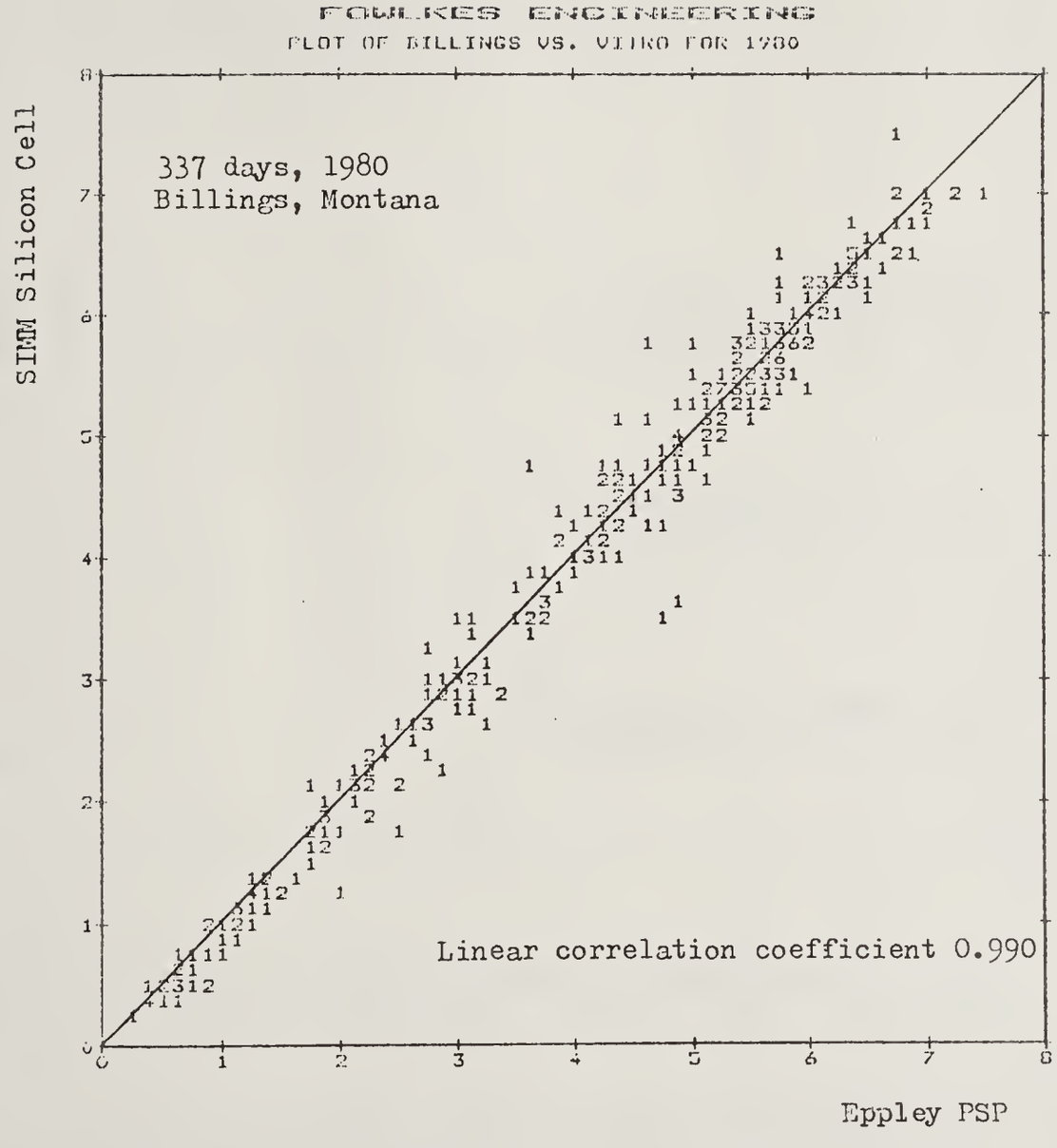


Figure 2. Scatter plot, daily totals, kWh-m^{-2}

Table 1. Daily Totals ($kWh-m^{-2}$) Billings, November, 1980

DAY	NSDN (PSP)	FOWLKES SIDN	NSDN LESS SIDN
1	2.59	2.66	-.07
2	2.18	2.13	.05
3	5.70	5.72	-.02
4	1.92	1.59	.33
5	6.07	6.16	-.09
6	1.51	1.25	.26
7	1.06	1.00	.06
8	4.41	4.78	-.37
9	1.06	1.06	.00
10	2.42	2.47	-.05
11	1.23	1.19	.04
12	0.65	0.63	.02
13	0.87	0.47	.40
14	5.27	5.06	.21
15	5.80	5.91	-.11
16	5.74	5.84	-.11
17	5.87	5.81	.06
18	2.92	2.84	.08
19	1.65	1.41	.25
20	3.76	3.84	-.08
21	1.82	1.84	-.03
22	0.58	0.50	.08
23	5.75	5.63	.13
24	2.28	2.22	.06
25	0.85	0.53	.31
26	5.17	4.63	.55
27	0.94	0.81	.13
28	5.80	5.31	.48
29	1.82	1.72	.11
30	0.39	0.38	.02
AVG	2.94	2.85	3.07%

Table 2. Monthly Average Daily Total ($kWh-m^{-2}$)

MONTH	NSDN (PSP)	FOWLKES SIDN
JAN	3.13	3.29
FEB	3.29	3.29
MAR	4.14	4.01
APR	5.23	5.18
MAY	4.77	4.74
JUN	4.84	4.82
JUL	5.25	5.15
AUG	4.75	4.73
SEP	4.80	4.72
OCT	*4.38	4.33
NOV	2.94	2.85
DEC	2.05	*1.88

*missing 8 to 10 days

Table 3. Bozeman Daily Totals ($kWh-m^{-2}$) November, 1980

DAY	KIPP	LI-COR	SIDN
1	2.80	2.84	2.72
2	1.95	1.94	1.88
3	1.01	0.99	0.93
4	2.04	2.07	1.96
7	0.42	0.44	0.39
8	4.21	4.22	4.13
9	1.39	1.39	1.31
10	1.40	1.32	1.30
11	0.54	0.55	0.53
12	1.14	1.15	1.12
13	5.67	5.62	5.44
14	*5.33	6.60	6.36
15	6.68	6.55	6.38
16	6.62	6.61	6.43
17	4.13	4.40	4.24
18	1.10	1.03	1.05
19	0.93	0.89	0.86
20	3.83	3.77	3.68
21	3.04	3.02	3.00
22	0.73	0.68	0.66
23	5.43	5.40	5.28
24	3.71	3.61	3.54
25	0.71	0.64	0.63
26	4.44	4.43	4.28
27	1.74	1.66	1.66
29	2.01	1.94	1.93
30	1.54	1.45	1.44
AVG	2.66	2.64	2.57

*Frost

RADIATION (kWh/M2) x 317 = RADIATION (BTU/ft^2)

Table 4. CLEAR DAY COMPARISONS

Station name	1977 * Clear days	1977 Deviation,% ** Orig.	1977 Deviation,% ** Adj.	1977 Class	1978 Clear days	1978 Deviation,% ** Orig.	1978 Deviation,% ** Adj.	1978 Class
Anaconda					21	4.0	3.4	II
Billings	20	5.2	2.06	I	56	4.7	3.3	I
Bozeman	27	4.1	2.8	I	58	4.1	2.8	I
Browning	34	8.5	2.5	II	38	5.1	3.4	I
Butte	25	7.4	2.2	II	15	5.1	2.9	I
Choteau					49	4.5	2.2	I
Colstrip	14	3.7	1.7	I	55	3.2	3.0	I
Dillon	46	8.0	6.1	III	56	5.9	4.1	II
Ennis					34	3.6	2.2	II
Fort Benton					33	4.9	1.8	II
Glasgow	58	9.1	2.3	II	65	7.2	3.1	II
Glendive	45	5.6	2.3	I	40	5.1	3.1	I
Great Falls	50	2.5	2.5	I	51	2.3	2.3	I
Hamilton	20	8.4	3.2	III	25	9.4	4.0	III
Harlowton	43	6.2	2.1	II	35	8.9	2.0	II
Havre	42	3.1	2.0	I	41	4.0	3.3	II
Helena	36	7.0	3.4	I	44	5.7	4.6	I
Jordan					55	10.2	3.5	III
Kalispell	35	3.3	3.01	I	42	5.3	5.1	II
Lewistown	36	6.8	2.5	I	34	8.2	2.3	III
Libby	28	2.1	2.5	I	34	5.7	3.6	II
Livingston					35	6.8	4.8	III
Miles City	45	5.0	1.7	II	41	3.5	3.5	I
Missoula	33	5.0	2.7	I	45	5.8	4.1	II
Plentywood					24	10.0	5.9	III
Polson	41	4.0	1.4	I	52	3.8	1.7	I
Red Lodge					45	9.6	4.3	III
Sidney					16	5.6	3.6	II
Thompson Falls					28	4.7	4.0	II
W. Yellowstone	27	11.1	3.2	III	46	11.1	5.6	III

* A "clear day" is a day that is clear for several hours around solar noon.

** Average absolute value of deviation for all clear days.

Table 4 (Continued)
1979 CLEAR DAY COMPARISONS

Station name	* Clear days	Deviation, %** Orig.	Adj.	Class
Anaconda	34	4.3	2.2	I
Billings	93	6.1	2.6	I
Bozeman	97	6.9	2.8	I
Browning	28	6.0	2.0	I
Butte	47	8.0	2.0	I
Choteau	74	3.6	3.6	I
Colstrip	20	8.6	4.7	II
Dillon	69	3.3	1.9	I
Ennis	69	2.6	2.5	I
Fort Benton	79	6.4	1.8	I
Glasgow	55	9.8	2.1	II
Glendive	58	4.1	2.0	I
Great Falls	98	3.0	2.1	I
Hamilton	72	9.5	3.2	II
Harlowton	60	7.7	1.4	I
Havre	54	4.3	2.7	I
Helena	64	5.5	2.6	II
Jordan	54	15.7	4.1	III
Kalispell	27	3.7	2.7	I
Lewistown	84	8.2	2.6	II
Libby	64	2.8	2.3	I
Livingston	27	5.1	2.0	I
Miles City	76	7.0	2.1	I
Missoula	69	5.7	2.3	I
Plentywood	39	7.1	4.3	II
Polson	43	3.6	2.0	I
Red Lodge	76	7.9	3.1	II
Sidney	64	3.0	2.3	I
Thompson Falls	19	4.2	3.0	II
West Yellowstone	60	11.3	2.8	II

* A "clear day" is a day that is clear for several hours around solar noon.

** Average absolute value of deviation for all clear days.

Table 4 (Continued)
1980 CLEAR DAY COMPARISONS

Station Name	*Clear Days	**Deviation % Orig.	Adj.	Class
Anaconda	27	5.9	1.7	II
Billings	69	10.0	2.1	I
Bozeman	56	5.9	1.9	I
Browning	25	6.8	1.3	I
Butte	46	7.6	2.2	I
Choteau	50	4.6	1.9	II
Colstrip	51	3.26	3.18	I
Dillon	49	2.7	2.5	I
Ennis	29	2.7	1.88	I
Fort Benton	61	5.7	1.5	II
Glasgow	66	2.8	1.7	II
Glendive	39	1.8	1.8	I
Great Falls	58	4.0	1.8	II
Hamilton	45	4.2	1.6	I
Harlowton	54	1.8	1.2	I
Havre	40	4.3	3.3	II
Helena	24	2.0	1.8	I
Jordan	77	13.0	2.3	II
Kalispell	29	2.0	1.6	I
Lewistown	50	1.4	1.4	I
Libby	30	3.1	1.6	II
Livingston	31	6.4	2.5	III
Miles City	79	4.4	1.9	II
Missoula	26	4.7	3.0	I
Plentywood	59	4.2	2.1	II
Polson	51	2.7	1.4	I
Red Lodge	48	7.1	3.1	II
Sidney	42	5.7	2.0	III
Thompson Falls	21	3.6	2.7	III
West Yellowstone	38	4.3	1.8	II

* A "clear day" is a day that is clear for several hours around solar noon.
** Average absolute value of deviation for all clear days.

Table 4 (Continued)

1981 CLEAR DAY COMPARISONS

Station Name	*Clear Days	**Deviation % Orig.	Adj.	Class
Anaconda	43	10.1	1.6	II
Billings	87	6.8	2.5	I
Bozeman	82	5.1	1.8	I
Browning	34	6.08	1.9	I
Butte	21	11.6	1.8	I
Choteau	68	3.5	1.99	I
Colstrip	78	4.39	1.9	I
Dillon	76	6.15	3.4	II
Ennis	47	9.6	1.87	I
Fort Benton	68	4.8	1.76	I
Glasgow	60	5.49	1.97	I
Glendive	66	5.1	1.59	I
Great Falls	91	3.9	1.6	I
Hamilton	68	4.8	1.27	I
Harlowton	25	2.08	1.4	I
Havre	69	2.9	2.2	I
Helena	64	14.5	2.15	II
Jordan	81	15.1	2.49	III
Kalispell	33	3.8	1.6	I
Lewistown	75	2.24	2.21	I
Libby	27	7.17	1.8	I
Livingston	40	4.8	1.6	I
Miles City	74	6.2	1.58	I
Missoula	16	5.9	2.4	II
Plentywood	33	6.36	2.75	III
Polson	40	3.8	2.1	I
Red Lodge	60	8.04	2.6	I
Sidney	30	6.5	1.81	I
Thompson Falls	42	3.8	1.9	II
West Yellowstone	36	8.03	2.76	II

* A "clear day" is a day that is clear for several hours around solar noon.

** Average absolute value of deviation for all clear days.

Table 4 (Continued)

1982 CLEAR DAY COMPARISONS

Station Name	*Clear Days	**Deviation % Orig.	Adj.	Class
Anaconda	27	12.5	2.16	II
Billings	74	4.4	1.7	I
Bozeman	77	7.5	3.3	II
Browning	71	4.9	2.3	I
Butte	44	11.2	2.4	I
Choteau	85	6.2	1.5	I
Colstrip	40	4.6	2.8	II
Dillon	73	9.8	3.8	II
Ennis	47	12.7	3.96	II
Fort Benton	82	6.9	1.9	I
Glasgow	39	15.5	3.7	II
Glendive	59	5.4	1.6	I
Great Falls	96	3.9	1.9	I
Hamilton	63	7.4	1.8	I
Harlowton	59	5.9	1.87	I
Havre	81	4.4	2.5	I
Helena	10	23.2	2.3	III
Jordan	81	18.8	2.98	II
Kalispell	53	3.6	2.7	I
Lewistown	86	2.5	1.4	I
Libby	48	6.9	4.87	I
Livingston	22	6.1	4.5	III
Miles City	74	9.8	2.6	I
Missoula	48	7.9	3.3	II
Plentywood	34	4.7	2.3	II
Polson	47	4.4	2.3	I
Red Lodge	61	6.4	3.07	II
Sidney	25	8.7	4.06	II
Thompson Falls	3	7.6	8.3	III
West Yellowstone	8	13.6	8.8	III

* A "clear day" is a day that is clear for several hours around solar noon.

** Average absolute value of deviation for all clear days.

APPENDIX II: SIMPLIFIED PERFORMANCE ESTIMATION

"We are all working together to one end,
some with knowledge and design, and others
without knowing what they do." Marcus Aurelius

1.0 INTRODUCTION

This section presents some highly simplified performance estimation procedures and system design considerations. The use of this information will insure that your design expectations will not be totally absurd. After these simplified procedures are used to rough out the design the designer should proceed to the more accurate detailed design procedures (a) and (b) listed below.

(a) To accurately estimate the performance of an active solar homeheating system or active solar domestic hot water system the designer should use the f-chart design procedure. The simplified f-chart procedures given in Appendix III of this Manual is adequate for all active solar systems of standard design to be used in Montana.

(b) Detailed design considerations and procedures for passive heating systems are given in the Passive Solar Design Handbook, Volumes 1 to 3, DOE/CS-0127, prepared for the U. S. Department of Energy Washington, D.C. 20585.

1.1 Some Basics to Keep in Mind

The cardinal rule in solar system design is Keep it Simple. Rube Goldberg design fantasies bristling with multiple heat exchangers, pumps, fans, controls, coils, valves, dampers, vents, etc., should generally be avoided. Use standard, proven designs.

A solar system is expensive, normally taking 10 to 20 years to pay for itself. It should therefore be designed to last longer than 20 years with minimal maintenance to be economically viable.

Solar radiation is a very diffuse form of energy. A surface, the size of this page will receive about 100 kWh (341,000 Btu) each year in Montana. A solar system will convert about 1/3 of this or 33 kWh (11,700 Btu) into usable energy. A typical household will need about 1000 times this amount of energy each year for heating, lighting and appliances.

Active solar systems move the solar energy through several heat exchangers before it is delivered to the end load. Inefficiences along the "links of this chain" will accumulate. For example, if there are three "links" that are only 80% as efficient as they should be the overall system will be 80% x .8 x .8 or 51% as efficient as it could be! All details of the system must therefore be designed, sized and built right to maintain acceptable performance.

The collector should not be shaded by trees or buildings. Even shade from a tree with no leaves will seriously reduce the heat output of a collector. The sun angles given in Section 3 will help determine shading.

Passive solar systems will need special glazing or movable insulation (to control heat loss) to achieve efficient performance in midwinter. If large areas of glass are used the heat storage system must be carefully designed and of adequate size. The temperature of a sunspace, having insufficient storage, can easily reach 95° on a sunny winter day.

The nemesis of active air solar systems is leakage. Special dampers should be used and all ductwork, collectors and plenums should be carefully sealed. A completed system should be tested for leaks.

Liquid collectors must be protected from freezing and the freeze protection must be 100% FAIL SAFE. The long term effects of corrosion should be carefully evaluated.

2.0 SHORT FORM SOLAR AND WEATHER DATA

The map in Figure 1 defines regions in Montana having similar amounts of solar radiation during the heating season. At least one data station has been selected for each region. The solar radiation and weather data for these stations has been condensed for use with the simplified performance estimation methods presented in this Appendix. Locate the region containing your site and select the nearest data station in the region.

The data tables, Table 1 through Table 10, show the total solar radiation each month (in 1,000's of Btu) striking an area of one square foot. The radiation is shown for collector tilts of 45° (for domestic hot water), 60° (for active space heating systems) and 90° (for passive space heating systems). Annual totals are given in the last column of the tables. Temperature and degree-day data in °F are also included to estimate heating

requirements.

Some blank summary tables are also included. The user can make up a custom table for any of the 30 stations. Use the daily average solar data for each month from Section 3 and correct for the tilt angle desired. Convert into monthly values and convert to the desired units. Transfer the temperature and degree day data from Section 7. .

2.1 SOLAR/LOAD Ratio Summary Map

The monthly total solar radiation is divided by the monthly total degree days to form the SOLAR/LOAD RATIO map for Montana. This data is presented for the heating season defined as October through April. The SOLAR/LOAD RATIO reflects the balance between "How much solar heat is available" and "How much space heating is needed".

The map in Figure 2 defines the relative impact of solar space heating on heating requirements. A given solar heating system will supply a larger percentage of the load in areas having a higher solar load ratio.

3.0 ACTIVE SOLAR SYSTEM PERFORMANCE ESTIMATION

The first step is to classify the collectors to be used as BEST, AVERAGE, or POOR. For example a well insulated, double glazed, selective surface liquid collector using low iron glazing would be BEST. A single glazed, front pass air collector with modest insulation and typical leakage would be POOR. (See TYPICAL COLLECTOR PERFORMANCE CURES, Figure 2 and 3, APPENDIX III for help). If in doubt assume your collector is AVERAGE.

The table below shows the expected average conversion efficiency for the three classes of systems. Conversion efficiency is the amount of energy delivered by the active solar system divided by the solar energy received on the surface of the collectors.

SYSTEM CLASSIFICATION	CONVERSION EFFICIENCY
BEST	.30 to .40
AVERAGE	.20 to .30
POOR	0 to .20

The solar heat collected is estimated by multiplying the solar radiation on the collector by the conversion efficiency.

SOLAR HEAT = SOLAR RADIATION X COLLECTOR AREA X CONVERSION EFFICIENCY

Example 1: Estimate the annual solar heat delivered by a high quality solar domestic hot water system in Billings. The collector is mounted at a 45° tilt and its area is $60 ft^2$.

We select a conversion efficiency of 0.35. The annual average solar radiation in Billings on a 45° surface is 505,000 Btu/ft^2 (See Table 1). The annual solar heat is 505,000 x 60 x 0.35 = 10,600,000 Btu.

Example 2: Estimate the annual solar heat delivered by a medium quality solar space heating system in Missoula. The collector is tilted at 60° and has an area of $350 ft^2$.

We select an average conversion efficiency of 0.25. The annual average solar radiation in Missoula on a 60° surface is 403,000 Btu/ft^2. The annual solar heat is 403,000 x 350 x 0.25 = 35,263,000 Btu.

The calculation above can be done on a month by month basis. Keep in mind that real collectors will be more efficient during warm weather than during the winter. Our simplifying assumption of constant conversion efficiency will consequently distort the monthly distribution.

4.0 PASSIVE SOLAR SYSTEM PERFORMANCE ESTIMATION

A "passive" solar system is normally a large area of south-facing glass incorporated into the south side of the building. This glass is usually vertical, (90°). The building itself becomes a low temperature solar collector. Since the building is at low temperature the conversion efficiency of this "collector" is quite high; ranging from 0.45 to 0.65 during the day.

The same glass that collects heat efficiently during the day will loose large amounts of heat during the night in cold weather. During a sunny, Montana, winter day a south facing window will gain heat for about 5 hours and lose heat for the other 19 hours! During a cloudy

day the window will lose heat for 24 hours a day.

The heat loss factor for a double glazed window is 0.58 Btu/hr-ft^2-$^\circ$F. The data tables show an average air temperature in Great Falls in December as 26.5°F. If the average interior air temperature of a building is 68°F the monthly heat lost through a window 1 square foot in area is 0.58Btu/hr-ft^2-$^\circ$F x 24 hr/day x 31 days/month x (68 - 26.5)$^\circ$F x 1 ft^2 = 17,900 Btu.

The monthly solar radiation on a 90° surface in Great Falls in December is 24,100 Btu/ft^2 (see Table 6). If the window transmits 0.65 of this solar radiation then 15,665 Btus of solar heat will be gained. The result is that the passive solar window loses more heat than it gains during this month.

This simple example illustrates a crucial issue of passive solar design in our climate: Unwanted heat loss through the large glazed areas severely limits the average performance of the passive solar system. Design solutions to this problem include movable insulation systems and special low-loss glazings. Since the glazing is losing heat over 80% of the time during an average day a reduction in this heat loss will dramatically improve the average solar system performance.

The solar heat collected by a south-facing glazed area can be estimated by the following equation

PASSIVE SOLAR HEAT = 0.6 x AREA x 90° SOLAR RADIATION

Example: How much solar heat will be gained by a vertical, south facing window having an area of 200ft^2 in Billings during February? The table shows 31,900 Btu/ft^2 solar radiation on a vertical surface in February in Billings.

SOLAR HEAT = .6 x 200 x 31,900 = 3,828,000 Btu

The additional heat load caused by the glazing is incorporated into the building load calculations. Compare the auxiliary energy requirements of the passive solar building with the auxiliary energy required by the same building without the passive solar glazing. The difference in auxiliary energy required is the net solar energy delivered by the passive system.

5.0 OTHER DESIGN RESOURCES

Design routines which can be implemented on personal computers or low cost hand calculators have been developed. Some programs are available in the literature and may be copied. Software for passive and active solar design are available from several commercial sources. (Look for advertisements in monthly periodicals such as Solar Engineering, Solar Age, Byte, Solar Heating & Cooling, or various "Guides" to solar equipment.)

Manufacturers of solar equipment usually provide some type of design support to help the user select properly sized components. Lists of manufacturers are available through government sources, trade journals and solar energy books available at many local bookstores.

The design services of local engineers, architects and heating contractors may be used. Names and addresses can be obtained through the appropriate professional organizations, trade organizations, DNR&C, or the Yellow Pages of the phone book. If you enlist the design services of consultants and manufacturers (especially those outside Montana) you should make them aware of the information in the Montana Solar Data Manual.

There has been a rapid growth in all areas of solar utilization in the past few years. In the late 1960's there were only about a dozen solar heated buildings in the United States; now there are thousands of solar homes completed or under construction. In Montana there is probably at least one solar home within 50 miles of your home. A number of these homes are "demonstration projects" funded by the Alternative Renewable Energy Sources Program of the Montana DNR&C and are available to the public for viewing. A person who is considering investing in a solar system should visit these homes.

The novice solar designer has an increasing resource base against which he can measure and improve his ideas. The novice designer would do well to keep in mind the adage "Those who neglect to study history are fated to repeat it". This Appendix began with a quote and ends with another quote. Remember both of them.

> A little learning is a dangerous thing:
> Drink deep, or taste not the Pierian spring:
> There shallow draughts intoxicate the brain,
> And drinking largely sobers us again.
>
> Alexander Pope

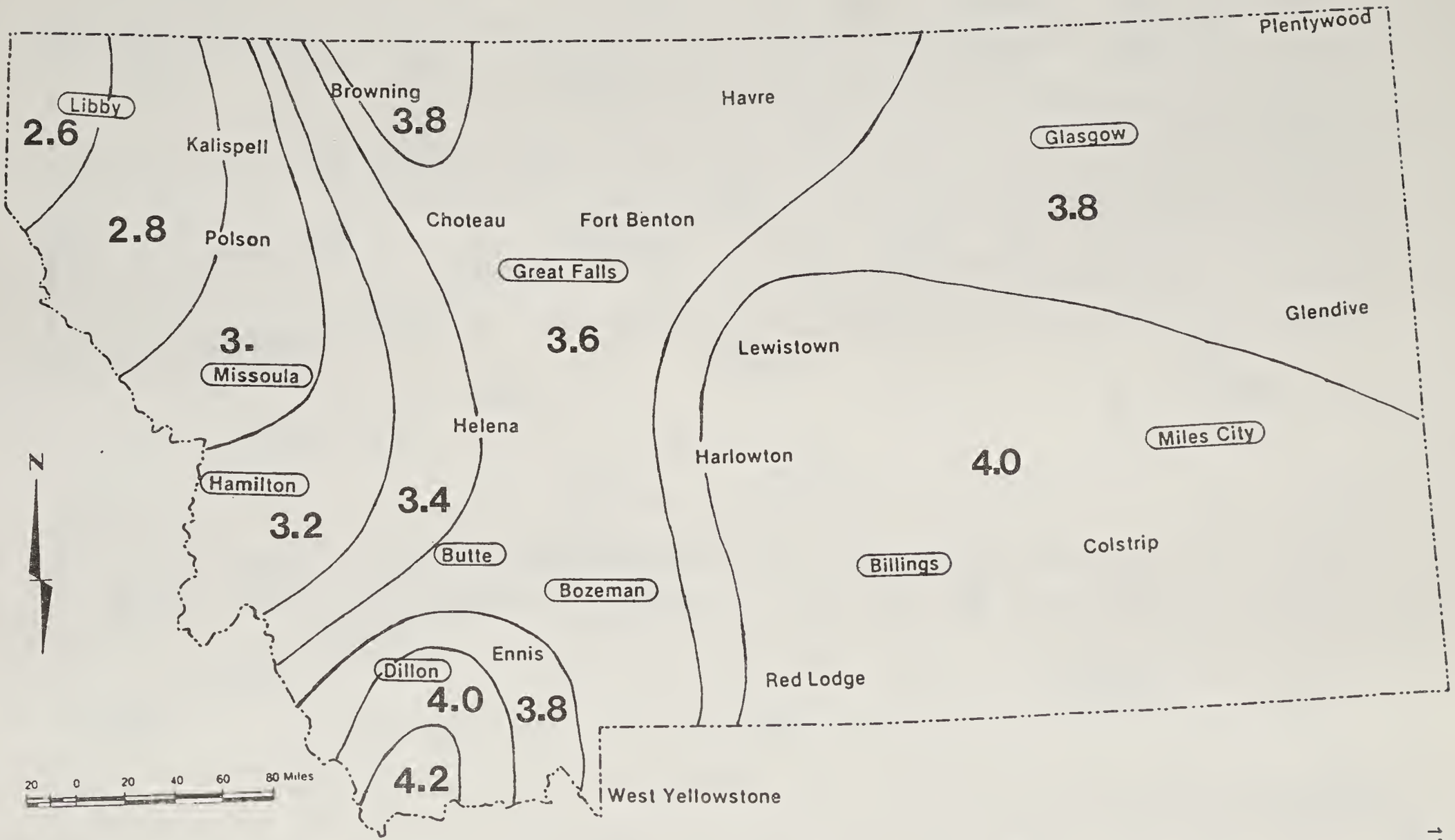


Figure 1: Average daily solar radiation, kWh/m^2, during heating season (October through April)

$$\text{SOLAR/LOAD RATIO} = \frac{\text{Monthly total solar radiation, Btu/ft}^2}{\text{Monthly total heating degree days, }^{\circ}\text{F-days}}$$

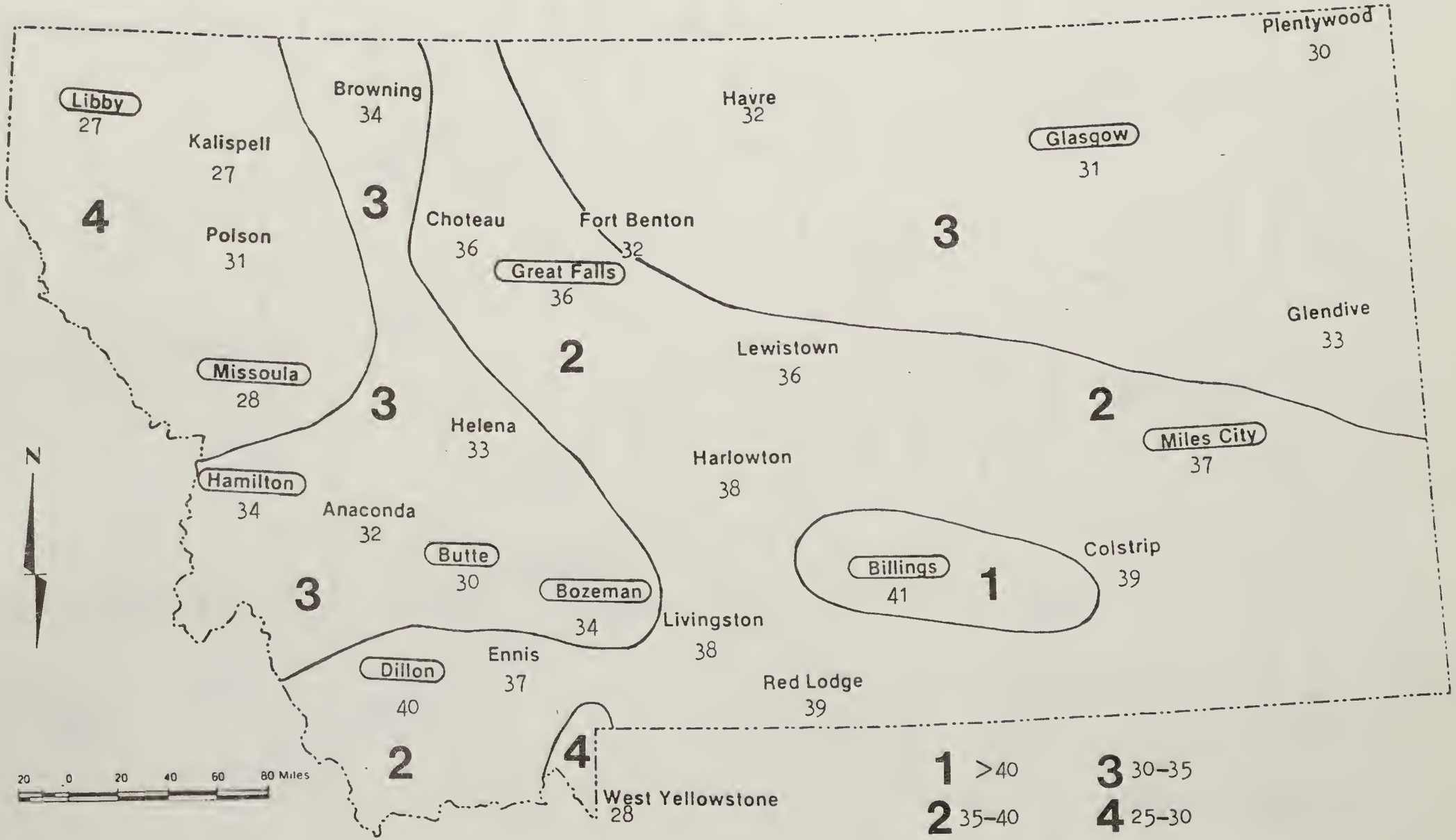


Figure 2: Montana SOLAR/LOAD Ratio Map Showing Four Regions

TABLE 1

SITE: Billings ELEVATION 3117 ft. LAT: 45.78 ° LONG: 108.50 °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	28.9	35.2	44.2	47.9	46.2	51.4	52.8	53.1	51.1	40.7	30.7	23.4	505.7
	60°	31.8	36.6	43.4	44.3	40.5	44.3	46.3	49.2	50.1	42.4	33.7	26.0	488.7
	*90°	29.9	31.9	34.3	30.6	24.7	25.3	27.8	33.9	39.1	36.9	31.7	25.0	371.0
Average temperature, °F		23.2	29.7	34.9	46.9	56.1	63.2	71.4	69.5	59.1	49.7	36.4	27.8	47.3
Degree-days, base 65°F		1296	988	933	543	288	121	11	23	221	474	858	1153	6909

*calculated

TABLE 2

SITE: Bozeman ELEVATION 4754 ft. LAT: 45.67 ° LONG: 111.03 °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	24.6	32.4	43.3	47.9	42.9	49.2	54.9	53.1	47.2	38.9	25.4	19.1	478.8
	60°	27.0	33.7	42.4	44.3	37.6	42.4	48.2	49.2	46.3	40.5	28.0	21.2	460.8
	*90°	25.4	29.4	33.5	30.6	22.9	24.2	28.9	33.9	36.1	35.2	26.3	20.4	346.7
Average temperature, °F		20.4	25.9	30.2	42.1	50.9	57.6	66.3	64.9	55.6	46.1	32.2	25.2	43.1
Degree-days, base 65°F		1372	1106	1074	680	429	232	45	70	288	581	976	1229	8082

*calculated

TABLE 3

SITE: Butte ELEVATION 5755 ft. LAT: 46.00° LONG: 112.50°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	28.1	33.3	41.3	47.9	40.7	45.8	51.7	50.0	45.2	37.0	28.9	20.8	470.7
	60°	30.8	34.7	40.5	44.3	35.7	39.5	45.3	46.3	44.3	38.6	31.8	23.1	455.0
	*90°	29.0	30.2	32.0	30.6	21.8	22.5	27.2	31.9	34.6	33.5	29.9	22.2	345.4
Average temperature, °F		15.1	20.9	25.6	37.7	46.8	53.9	62.2	60.3	50.6	41.1	27.9	19.2	38.4
Degree-days, base 65°F		1547	1235	1221	819	564	337	119	166	437	741	1113	1420	9719

*calculated

TABLE 4

SITE: Dillon ELEVATION 5057 ft. LAT: 45.25° LONG: 112.63°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	29.8	38.9	46.2	52.1	47.3	52.6	57.1	53.1	51.1	42.6	33.3	23.4	527.5
	60°	32.8	40.5	45.3	48.2	41.5	45.3	50.1	49.2	50.1	44.3	36.6	26.0	510.0
	*90°	30.8	35.2	35.8	33.3	25.3	25.8	30.1	33.9	39.1	38.6	34.4	25.0	387.3
Average temperature, °F		22.2	27.4	31.5	42.1	50.7	57.5	65.1	63.4	54.7	46.1	33.5	25.7	43.3
Degree-days, base 65°F		1327	1053	1039	687	443	235	50	100	319	586	945	1218	8002

*calculated

TABLE 5

SITE: Glasgow ELEVATION 2095 ft. LAT: 48.20° LONG: 106.63°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	26.3	36.1	45.2	46.9	49.5	55.9	58.2	51.0	47.2	39.8	27.2	20.8	504.1
	60°	28.9	37.6	44.3	43.4	43.4	48.2	51.1	47.2	46.3	41.5	29.9	23.1	484.9
	*90°	27.2	32.7	35.0	29.9	26.5	27.5	30.7	32.6	36.1	36.1	28.1	22.2	364.5
Average temperature, °F		10.5	14.5	28.4	44.4	55.5	63.6	72.2	68.9	57.2	45.5	28.0	15.8	42.0
Degree-days, base 65°F		1690	1414	1135	618	330	131	15	34	262	605	1110	1525	8869

*calculated

TABLE 6

SITE: Great Falls ELEVATION 3330 ft. LAT: 47.52° LONG: 111.30°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	24.6	33.3	43.3	47.9	46.2	52.6	56.0	52.1	47.2	37.9	28.1	22.6	491.6
	60°	27.0	34.7	42.4	44.3	40.5	45.3	49.2	48.2	46.3	39.5	30.8	25.1	473.3
	*90°	25.4	30.2	33.5	30.6	24.7	25.8	29.5	33.3	36.1	34.4	29.0	24.1	356.5
Average temperature, °F		20.5	26.6	30.5	43.4	53.3	60.8	69.3	67.4	57.3	48.3	34.6	26.5	44.9
Degree-days, base 65°F		1380	1075	1070	648	367	162	18	42	260	524	912	1194	7652

*calculated

TABLE 7

SITE: Hamilton ELEVATION 3600 ft. LAT: 46.25 ° LONG: 114.15 °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	18.4	28.7	39.3	47.9	41.8	49.2	52.8	51.0	42.3	37.9	23.7	15.6	448.6
	60°	20.2	29.9	38.6	44.3	36.6	42.4	46.3	47.2	41.5	39.5	26.0	174.	429.9
	*90°	19.0	26.0	30.5	30.6	22.3	24.2	27.8	32.6	32.3	34.4	24.5	16.7	320.9
Average temperature, °F		24.8	31.2	36.2	45.7	53.5	59.8	67.5	65.5	56.7	46.5	34.8	27.9	45.8
Degree-days, base 65°F		1246	946	893	579	362	171	27	66	267	574	906	1150	7187

*calculated

TABLE 8

SITE: Libby ELEVATION 2053 ft. LAT: 48.40 ° LONG: 115.58 °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	15.8	20.4	35.4	44.8	42.9	49.2	51.7	50.0	41.3	29.6	13.2	13.0	4073
	60°	17.4	21.2	34.7	41.5	37.6	42.4	45.3	46.3	40.5	30.8	14.5	14.5	386.7
	*90°	16.3	18.5	27.4	28.6	22.9	24.2	27.2	31.9	31.6	26.8	13.6	13.9	282.9
Average temperature, °F		22.0	28.0	36.4	45.8	54.4	60.4	67.5	65.3	57.0	46.3	32.5	26.8	45.2
Degree-days, base 65°F		1290	991	919	596	341	159	48	64	252	613	985	1179	7437

*calculated

TABLE 9

SITE: Miles City ELEVATION 2364 ft. LAT: 46.42° LONG: 105.82°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	30.7	37.0	46.2	50.0	45.1	53.7	53.8	51.0	48.2	40.7	27.2	21.7	505.3
	60°	33.7	38.6	45.3	46.3	39.5	46.3	47.2	47.2	47.2	42.4	29.9	24.1	487.8
	*90°	31.7	33.5	35.8	31.9	24.1	26.4	28.3	32.6	36.8	36.9	28.1	23.1	369.4
Average temperature, °F		16.5	20.3	30.9	45.7	57.4	65.6	75.3	72.6	61.0	49.0	32.6	23.2	45.8
Degree-days, base 65°F		1504	1252	1057	579	276	99	6	6	174	502	972	1296	7723

*calculated

TABLE 10

SITE: Missoula ELEVATION 3223 ft. LAT: 46.87° LONG: 114.00°

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°	18.4	25.0	36.4	41.6	40.7	49.2	49.5	50.0	42.3	35.2	20.2	13.0	421.4
	60°	20.2	26.0	35.7	38.6	35.7	42.4	43.4	46.3	41.5	36.6	22.2	14.5	403.0
	*90°	19.0	22.6	28.2	26.6	21.8	24.2	26.0	31.9	32.3	31.9	20.8	13.9	2993
Average temperature, °F		19.4	25.7	34.7	44.7	53.6	60.2	68.4	66.1	55.8	44.9	31.9	23.6	44.1
Degree-days, base 65°F		1414	1100	939	609	365	176	22	57	292	623	993	1283	7873

*calculated

SITE: ELEVATION ft. LAT: ° LONG: °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°													
	60°													
	*90°													
Average temperature, °F														
Degree-days, base 65°F														

*calculated

SITE: ELEVATION ft. LAT: ° LONG: °

	TILT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
SOLAR RADIATION thousands of Btu per ft^2	*45°													
	60°													
	*90°													
Average temperature, °F														
Degree-days, base 65°F														

*calculated

APPENDIX III: F-CHART DESIGN PROCEDURE FOR ACTIVE SOLAR SYSTEMS

1.0 INTRODUCTION

An exhaustive review of the literature describing solar system design and economic analysis procedures is beyond the scope of this Data Manual. Details of design procedures are described in many of the references listed in this Manual. These references are generally available from (a) local library resources such as Montana On-Line Reference Service; (b) government agencies (DOE, HUD, NBS, SERI, Government Printing Office); and (c) directly from the author of the reference.

Detailed simulation methods using large computers have been developed and used for research purposes and for the design of large and complex solar installations. These programs usually require hourly solar and weather data along with a detailed description of the solar system components and control system. The use of these precise methods is usually not economically justified for the design of small systems for a home or small commercial building.

Several simplified methods have been developed which use monthly average solar and weather data (such as the data given in this Manual). These methods have been developed under various government sponsored research projects and are available to the general public. The inclusion of these design methods in this Manual does not constitute an endorsement of these procedures. The methods were selected for review because they are widely used and are generally available. The individual solar designer must select a design method appropriate to the requirements of his project.

1.1 What is F-Chart?

F-chart is a method for predicting the performance of active solar heating systems. It uses readily available information such as solar collector specifications, estimates of heating load, and weather data to calculate the fraction of the heating load, f, which solar energy would provide for a particular design. F-chart is therefore quite useful in the design process for sizing systems and estimating system economics and energy savings.

A complete discussion of the f-chart method including all necessary weather data for 100 U.S. and Canadian cities is given in Solar Heating Design by the f-Chart Method; Beckman, Klein and Duffie; Wiley, 1977. The method was developed by the Solar Energy Laboratory of the University of Wisconsin. It represents a correlation of the results of numerous system simulations using the computer program TRNSYS (Transient System Simulation), also developed at the University of Wisconsin. The method has been set up for hand calculation using a series of standard forms and tables. It has also been programmed onto microcomputer format which is available from F-CHART SOFTWARE, 4406 Fox Bluff Road, Middleton, Wisconsin, 53562. The simplified method presented in this Appendix is based entirely on this work.

F-chart can be used for predicting the performance of active domestic hot water, space heating, or combined systems. F-chart is especially useful for design of domestic hot water systems because of the greater accuracy with which hot water heating loads may be estimated. It is most accurate when used on reasonably standard designs using standard amounts of thermal storage and having reasonable efficiency and heat losses. For such systems, the f-chart predictions have been found to agree well with actual field data. Methods have been developed to account for effects of non-standard collector fluid flowrate and thermal storage. These are described in the above book.

1.2 What is Simplified F-Chart?

The simplified f-chart method presented here attempts to reduce the amount of engineering calculations required for estimating system performance by using assumed values for certain parameters. Use of the solar radiation data in Section 3 of this manual also greatly simplifies the method, because solar radiation data is given there for the tilted plane of the collector. This eliminates the somewhat tedious calculation of tilted plane solar radiation from the horizontal plane solar radiation generally tabulated by the Weather Bureau. Such a calculation is required in the full f-chart method.

1.3 What Solar System may be Analyzed with Simplified F-Chart?

Simplified f-chart may be used to estimate the fraction by solar

for domestic hot water, space heating, or combined active solar heating systems. Either liquid or air systems may be considered. The method is most accurate for flat plate collector systems of at least approximately known thermal specifications. It may be used for approximate analysis of evacuated tubular collector systems, site-built air collector systems for which only estimated collector thermal specifications are available or for systems utilizing complex control or thermal storage strategies. (These restrictions apply to the full f-chart method as well). Typical collector efficiency curves are included for use when test data is not available.

1.4 How Accurate is Simplified F-Chart?

The accuracy of any solar performance estimation method is limited primarily by the accuracy of the inputs; heating load and weather data. Heating loads may vary from estimated values by 25% or more, especially in the case of space heating loads which have been estimated from handbook data. Weather parameters may vary from year to year by 25% or more.

The accuracy of the simplified f-chart method itself, assuming perfectly accurate input, is probably better than 25% for any system and considerably better for domestic hot water systems of standard design. For those interested in improving this portion of the accuracy, the full f-chart method should be used for systems having at least one of the characteristics below:

1. The amount of thermal storage is <u>not</u> between 1.5 and 3 gallons of water (liquid systems) or 0.6 to 1 cubic feet of rock (air systems) per square foot of solar collector.
2. The air flow rate through each collector panel for air systems is <u>not</u> between 1 and 4 cubic feet of air per minute per square foot of solar collector.
3. The collector orientation is <u>not</u> within $\pm$ 15° of true south.
4. The heat exchanger, if present, which transfers heat from the fluid heated in the solar collectors to the load is <u>not</u>

of standard engineering design.

Such corrections are seldom warranted because heating load and weather data contain larger approximations.

Table 1 lists recommended system parameters for active solar heating systems in Montana.

1.5 How Does Simplified F-Chart Work?

Simplified f-chart will estimate monthly and yearly solar fraction and solar and backup heat rates by following the three steps below. All data is entered on the Worksheet shown in Figure 1. This Worksheet can be used as a master to reproduce working copies using an office copier. In general, there are three kinds of inputs to the method:

1. System parameters; constant thermal parameters of the system including solar collector efficiency factors, hot water usage, and building heat loss coefficient.
2. Collector area; also a system parameter but the one typically varied in the design process to determine optimum performance.
3. Weather data; average solar radiation on the tilted surface, heating degree days, and average temperature. These are tabulated in earlier sections of the manual.

And there are two kinds of output:

1. Solar fraction; the monthly and yearly fraction of the heating load provided by solar energy.
2. Solar and backup heat rates; monthly and yearly energy supplied from the sun and by backup to meet the total heating load.

Use is made of the metric system of units in this Appendix because the solar radiation data in this Manual is given in metric units. (A units conversion table is presented in Appendix V.

2.0 STEP BY STEP SIMPLIFIED F-CHART PROCEDURE

STEP 1: ESTIMATE SYSTEM PARAMETERS

There are five constant system parameters which must be estimated.

a. Heat Exchanger Factor (B)

A heat exchanger may be present in the system to transfer heat from the fluid heated in the solar collectors to the thermal storage. Choose B from the following table and enter it at the bottom of the Worksheet, Figure 1.

Situation	Heat Exchanger Factor (B)
No heat exchanger used	1
Heat exchanger used	0.9

Heat exchangers of non-standard engineering design should be treated using the full f-chart method for improved accuracy.

b. Solar Collector Heat Loss Factor (C)

The thermal performance of flat plate solar collectors is typically expressed by two factors. These are measured in a standard manner (ASHRAE 93-77) and reported in the thermal specifications section of the collector data sheets. The collector heat loss factor, C, is labeled "$F_r U_L$" on most data sheets, or given as the slope of the efficiency curve. C must be used in metric units in this method; $W/^oC\text{-}m^2$. If it is reported in english units, $BTUh/^oF\text{-}ft^2$, multiply it by 5.67.

If C cannot be determined from the collector data sheets, Figure 2 (for liquid collectors) or Figure 3 (for air collectors) should be used to determine C for the type of collector used. The value of the Collector Heat Loss Factor should be entered at the bottom of the Worksheet.

c. Solar Collector Glazing Factor (D)

The solar collector glazing factor, D, is the other standard thermal performance factor reported in the thermal specification section of collector data sheets. D is labeled $F_r(\tau\alpha)$ on most data sheets or given as the y-intercept of the efficiency curve. It is dimensionless. If D cannot be determined from the collector data sheets, Figure 2 (for liquid

collectors) or Figure 3 (for air collectors) should be used to determine D for the type of collector used. The Collector Glazing Factor should be entered at the bottom of the Worksheet.

d. Water Heating Load (Q_W)

The water heating load, Q_W, is the monthly energy required for heating domestic hot water. Q_W depends on hot water consumption, and hot and cold water supply temperatures. An estimate for Q_W should be taken from the following table:

Number in Family	Water Heating Load (Q_W)
2	205 kWh/month
4	380 kWh/month
6	560 kWh/month

(These figures assume 20 gal/capita-day for the first occupant, and 15 gal/capita-day for additional occupants, and temperature rise of 80°F. If more accurate figures are known they should be used. See the f-chart book for treatment of variable cold water supply temperature). If no solar water heating is included in the design, the value of Q_W should be set to zero. The estimated Water Heating Load, Q_W, should be entered at the bottom of the Worksheet.

e. Building Heat Loss Factor (L)

The building heat loss factor, L, represents the overall "UA" of the building, including infiltration. It is the most difficult of the system parameters to accurately determine. It is beyond the scope of this Manual to discuss the various methods available for the calculation of the building heat loss factor. If the reader is not familiar with such calculations, he should either consult an appropriate reference listed in a later Appendix or make a very approximate determination of L from the following table:

For Buildings Which Are	Multiply the Floor Area in Square Feet by This Factor to Generate an Estimate of L in kWh/°C-Day
Well insulated and sealed	0.0026
Moderately well insulated and sealed	0.0053
Poorly insulated and sealed	0.008

The value of the Building Heat Loss Factor, L, should be entered at the bottom of the Worksheet. If solar space heating is not being considered, this calculation may be eliminated.

EXAMPLE: A solar water and space heating system is being designed for a family of four in Billings. The collectors are liquid type and are double glazed with the absorber painted black. No data sheets are available for the collectors. A heat exchanger is used. No building heat loss factor is available but the house is well insulated and sealed and has 1800 ft^2 of living area. A tilt angle of 50^o is selected.

The system parameters are:

B = .9 (heat exchanger is used)

C = 4.3 $w/^oC-m^2$ (from Figure 2, collector type 2)

D = .6 (from Figure 2, collector type 2)

Q_w = 380 kWh/month (family of four)

L = 4.7 $kWh/^oC$-day (1800 ft^2 x 0.0026; well insulated and sealed)

STEP 2: CHOOSE COLLECTOR AREA (A)

The collector area is the parameter most often chosen for system optimization. Because factory built solar collectors are expensive, the number of collectors significantly affects system costs and hence payback. Also, diminishing returns will set in; as collectors are added to the system, the incremental increase in solar fraction will taper off.

If the number of solar collectors is not yet fixed, it is recommended that an initial design value of A be calculated from the number of collectors given in the following table:

System Type	Family Size	Number of Collectors	Typical Collector Area (m^2)
Water Heating	2	2	3 - 8
	4	3	
	6	4	
Space heating or combined	-	10	20 - 50

It will be necessary to determine the area of each solar collector from the collector data sheets, in square meters. If the collector area is given in square feet, divide by 10.76. Enter the Collector Area, (A), at the bottom of the Worksheet. The system performance may then be estimated using Step 3.

Because the values of the correlation parameters X and Y (heating load factor and solar availability factor) are proportional to A, the monthly performance for other values of collector area may be easily determined without the somewhat tedious process of STEPS 1, 2, and 3.

A collector tilt of about 60° is normally used for winter collection of solar radiation for space heating in Montana. For domestic water heating a tilt of 45 to 50° would be typical. Enter Collector Tilt on Worksheet.

EXAMPLE: Collector data sheets were not available, but the aperature area of a single collector is measured to be 18 ft^2. The initial design collector area will be:

$A = (15 \text{ collectors} \cdot 18 \text{ ft}^2/\text{collector})/10.76 \text{ m}^2/\text{ft}^2 = 25 \text{ m}^2$

STEP 3: CALCULATION PROCEDURE

Calculation of monthly heating load factors, X, solar availability factors, Y, monthly and yearly solar fractions, and heat rates should be done using the Worksheet, Figure 1. Values of A, B, C, D, L, Q_W and tilt determined in STEPS 1 and 2 should now be entered at the bottom of the Worksheet. Then:

a. Copy the value of Q_W from the bottom of the worksheet into Column (2) for all months. (If solar water heating is not included in the design, all values Q_W in column (2) should be zero.)

b. Copy the monthly heating degree days (^{o}C) for the site (from the climatological data in Section 7 of the Manual) into column (3). (Since the climatological data is given in both Celsius and Fahrenheit, care should be taken to use degree days in degrees Celsius.)

c. Calculate the space heating load, Q_s, by multiplying the values in column (3) by the building heat loss factor, L, and entering the result in column (4). (If solar space heating is not included in the design, all values of Q_s in column (4) should be zero.)

d. Calculate the total heating load, Q, by adding columns (2) and (4) and entering the result in column (5). Sum the values in column (5) to obtain the yearly heating load and enter the result in block (15).

e. Copy the values of daily average temperature for the site, T, from the climatological data in Section 7 of the Manual into column (6). (The climatological data is given in both Celsius and Fahrenheit and care should be taken to use daily average temperature in degrees Celsius.)

f. Calculate the reference temperature difference by subtracting the values of T in column (6) from 100 and enter the results in column (7).

g. Calculate the monthly heating load factor, X, by multiplying the value of A·B·C by the value in column (7) and by 0.72. Then divide by the value in column (5) and enter the results in column (8).

h. Copy the values of daily average solar radiation for the site, S, from Overall Averages, Section 3, of the Manual into column (9).

i. Copy the collector tilt correction factors for the desired tilt angle from Section 3 of the Manual into column (10).

j. Calculate the solar availability factor, Y, by multiplying the value for A·B·D by values in columns (9) and (10) and by 30. Then divide by the value in column (5) and enter the results in column (11).

k. Using the f-chart correlations shown in Figure 4, determine values of the monthly solar fraction, f, and enter in column (12). This can be done by plotting the point (X,Y) onto the correct f-chart (liquid or air system) and interpolating the values of f from the curves immediately above and below the point (X,Y). Because this method is an approximate one for many reasons, a guesstimated interpolation is completely adequate. The values should be entered into column (12). This value, f, is the fraction of the total heating load which the solar system is contributing.

l. Calculate the monthly solar energy delivered to the heating load by multiplying the values in column (5) by the values in column (12) and entering the results in column (13). Sum this column to yield the yearly solar energy delivered to the heating load and enter in block (16).

m. Calculate the monthly backup energy needed by subtracting the values in (13) from the values in column (5) and entering the results in column (14). Subtract the value in block (16) from the value in block (15) to yield the yearly backup energy required, and enter the result in block (17).

n. Calculate the yearly solar fraction by dividing the value in block (16) by the value in block (15). This is the fraction of the yearly total heating load which the solar heating system is designed to contribute. (The monthly solar fractions cannot be combined directly to yield a yearly solar fraction because of the nonlinearity of the f-chart correlations.)

EXAMPLE: A sample completed worksheet for the example system is shown in Figure 5. The annual solar fraction for this system was 45%.

TABLE 1
DESIGN RECOMMENDATIONS FOR ACTIVE SOLAR SPACE HEATING SYSTEMS IN MONTANA*

	LIQUID SYSTEMS	AIR SYSTEMS
Collector Slope and Orientation	Tilted up 50 to 90° from horizontal, facing true south ± 15°	
**Flow rate	0.015 $l/s\text{-}m^2$ (0.022 gpm/ft^2)	5 to 20 $l/s\text{-}m^2$ (1 to 4 cfm/ft^2)
Storage media	Water tank	Pebble bin, 1 to 3 cm. diameter (0.5 to 1.5 in.)
Volume	50 to 100 l/m^2 (1 to 2 gal/ft^2)	0.15 to 0.35 m^3/m^2 (0.5 to 1.15 ft^3/ft^2
Cautions	Design & install collectors to prevent any possibility of freezing.	Carefully seal ducts, collectors & storage to prevent leaks. Test final system for leaks.

* Adapted from Solar Heating Design by the f-Chart Method, Beckman, Klein and Duffy, John Wiley and Sons.
**per unit collector area

Figure 1

SIMPLIFIED f-CHART WORK SHEET

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
MONTH	WATER HEATING LOAD	HEATING DEGREE DAYS	SPACE HEATING LOAD	TOTAL HEATING LOAD	AVERAGE TEMP	REFERENCE TEMP DIFF	HEATING LOAD FACTOR	DAILY AVG SOLAR RADIATION	TILT CORRECTION FACTOR	SOLAR AVAIL FACTOR	SOLAR FRACTION	SOLAR ENERGY	BACK-UP ENERGY
	$\frac{kWh}{month}$	^{o}C-days	$\frac{kWh}{month}$	$\frac{kWh}{month}$	^{o}C	^{o}C	X	$\frac{kWh}{m^2\text{-day}}$		Y		$\frac{kWh}{month}$	$\frac{kWh}{month}$
	Q_W	DD	$Q_s = L \cdot (3)$	$Q = (2) + (4)$	T	100 − (6)	$\frac{0.72 \cdot (7) ABC}{(5)}$	S		$\frac{30 \cdot ABD \cdot (9) (10)}{(5)}$	f	(5) · (12)	(5) − (13)
JAN													
FEB													
MAR													
APR													
MAY													
JUN													
JUL													
AUG													
SEP													
OCT													
NOV													
DEC													
YEARLY TOTALS				kWh/year (15)								kWh/year (16)	kWh/year (17)

Annual Solar Fraction = _____

Q_W = Water Heating Load = _____ $\frac{kWh}{month}$

A = Collector Area = _____ m^2

B = Heat Exchange Factor = _____

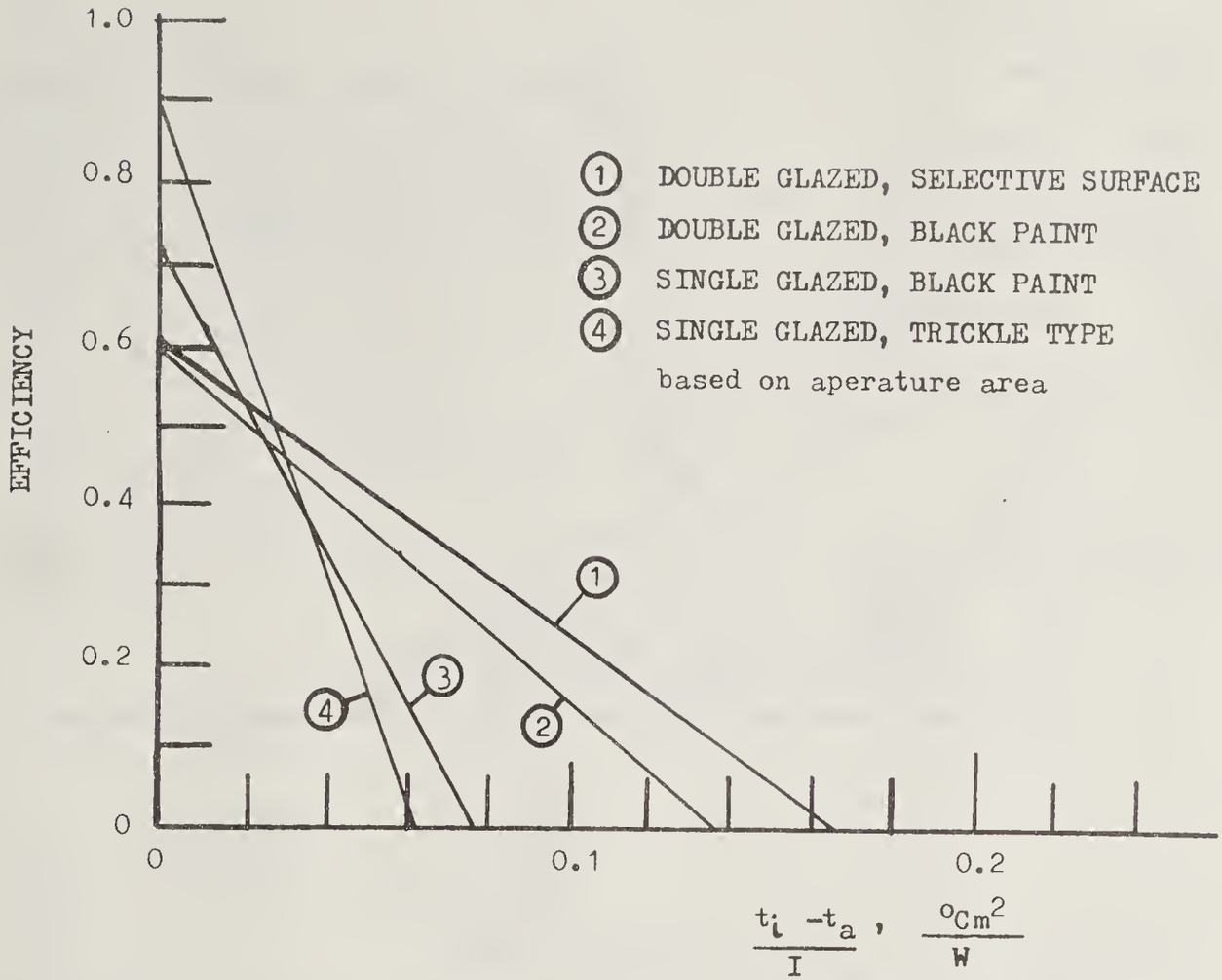
C = Collector Loss Factor = _____ $\frac{W}{^{o}C\text{-}m^2}$

D = Collector Glazing Factor = _____

L = Building Heat Loss Factor = _____ $\frac{kWh}{^{o}C\text{-day}}$

Collector Tilt = _____ degrees

Figure 2
TYPICAL LIQUID COLLECTOR PERFORMANCE CURVES



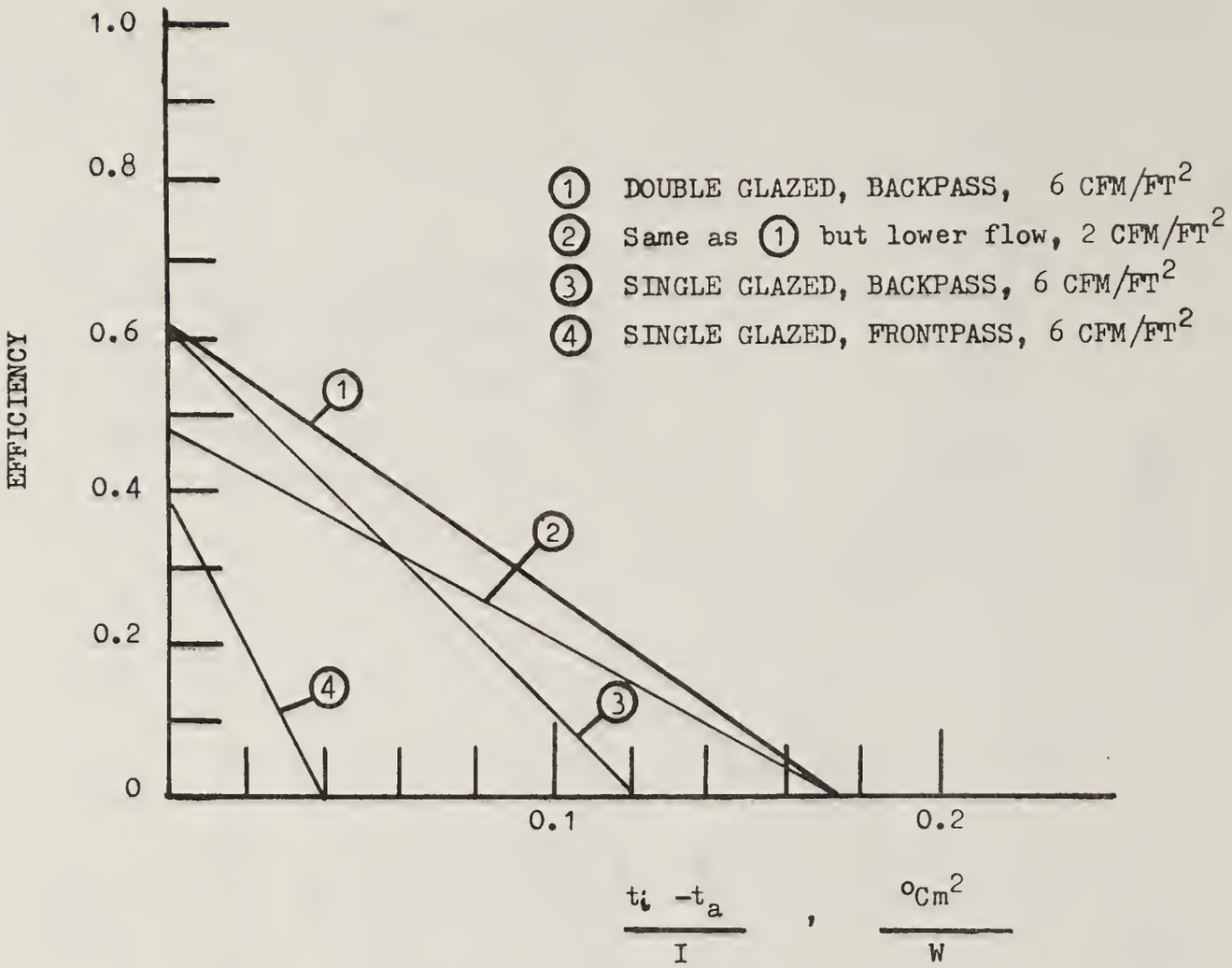
TYPE	$F_R(\tau\alpha)$	D^* $F_R U_L$ $\frac{W}{^oC\text{-}m^2}$	C^{**} C $\frac{Btu}{^oF\text{-}ft^2}$
1	0.6	3.5	0.61
2	0.6	4.3	0.75
3	0.73	9.1	1.60
4	0.90	13.8	2.42

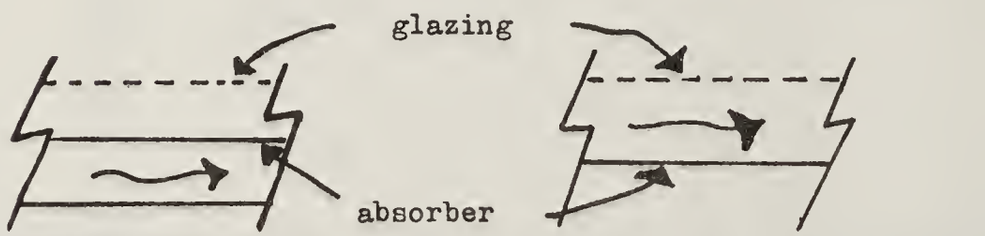
* Y-intercept

** slope = Y-intercept/X-intercept
enter these values on worksheet

Figure 3

TYPICAL AIR COLLECTOR PERFORMANCE CURVES

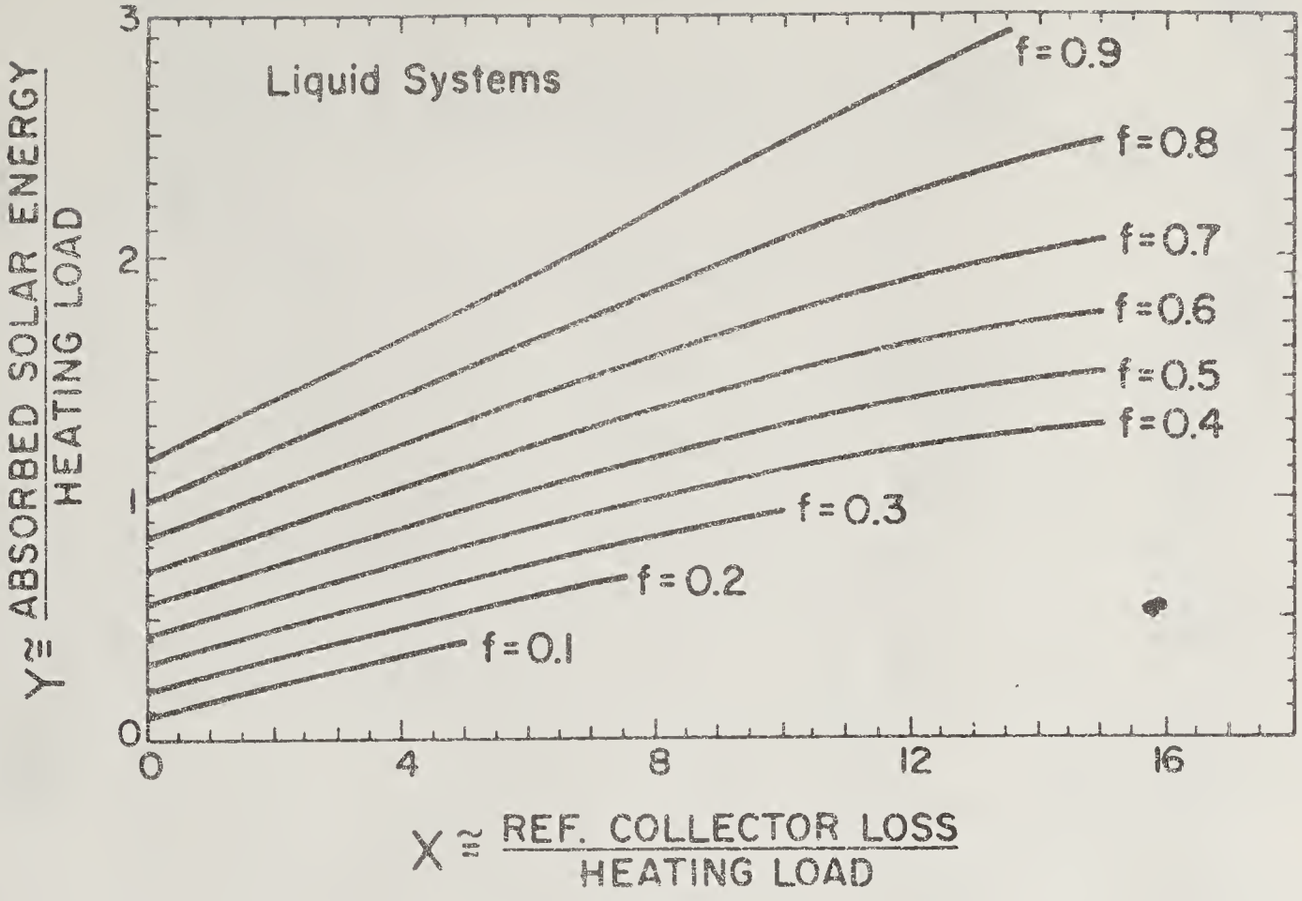




backpass, air flow under absorber

frontpass, air flow between absorber and glazing

TYPE	D $F_R(\tau\alpha)$	C $F_R U_L$, $\frac{W}{^oC-m^2}$	C $\frac{Btu}{^oF-ft^2}$
1	0.6	3.5	0.61
2	0.48	2.8	0.49
3	0.6	5.0	0.88
4	0.4	10.0	1.76



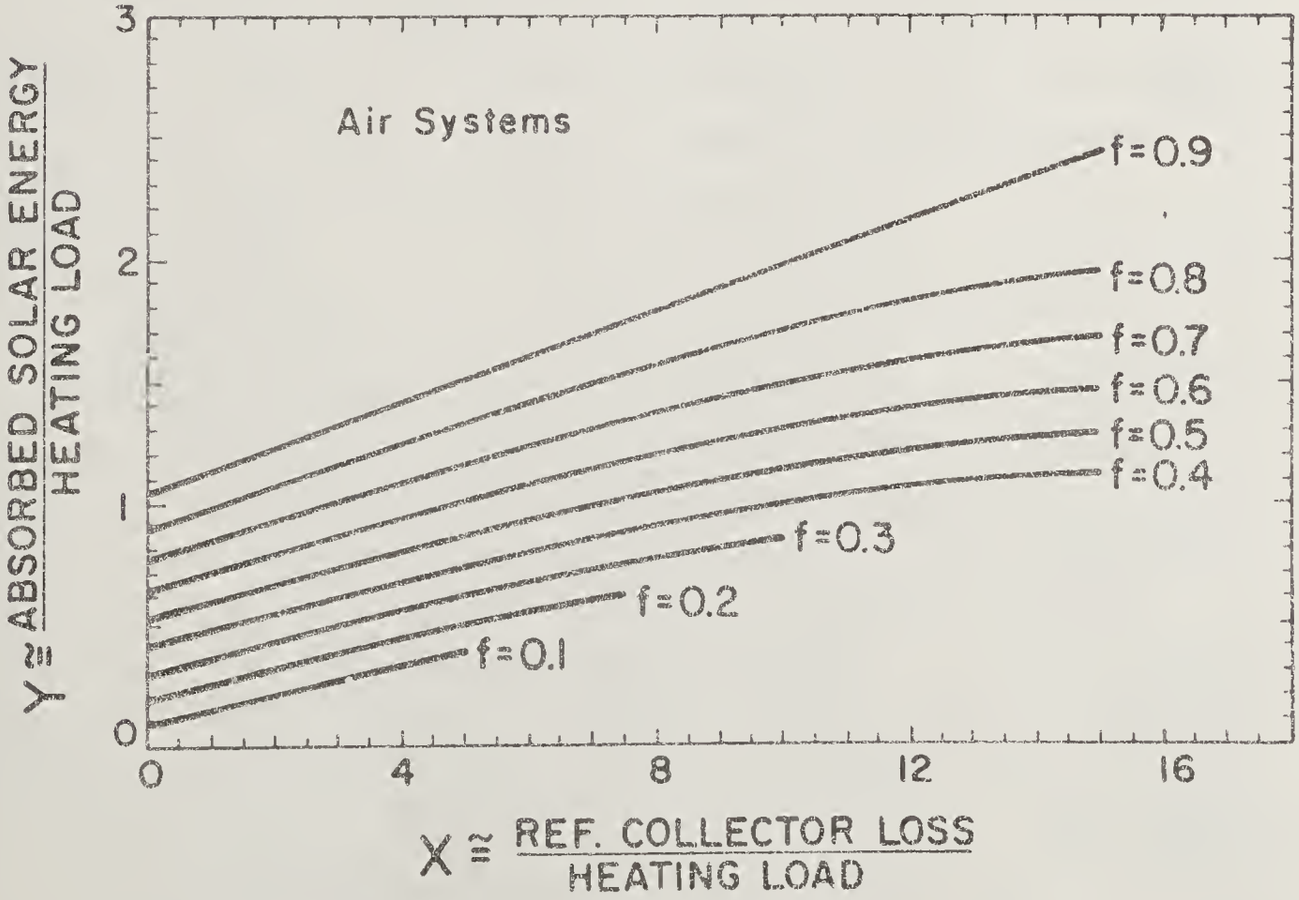


Figure 4: f-Chart Correlations
from, Solar Heating Design by the f-Chart Method; Beckman, Klein and Duffie

Figure 5: Sample Worksheet for Billings Example

SIMPLIFIED f-CHART WORK SHEET

(1) MONTH	(2) WATER HEATING LOAD	(3) HEATING DEGREE DAYS	(4) SPACE HEATING LOAD	(5) TOTAL HEATING LOAD	(6) AVERAGE TEMP	(7) REFERENCE TEMP DIFF	(8) HEATING LOAD FACTOR	(9) DAILY AVG SOLAR RADIATION	(10) TILT CORRECTION FACTOR	(11) SOLAR AVAIL FACTOR	(12) SOLAR FRACTION	(13) SOLAR ENERGY	(14) BACK-UP ENERGY
	kWh/month	°C-days	kWh/month	kWh/month	°C	°C	X	kWh/m²-day		Y		kWh/month	kWh/month
	Q_W	DD	$Q_S = L \cdot (3)$	$Q = (2)+(4)$	T	100−(6)	$\frac{0.72 \cdot (7) - ABC}{(5)}$	S		$\frac{30 \cdot ABD \cdot (9)/10}{(5)}$	f	(5)·(12)	(5)−(13)
JAN	380	720	3413	3793	−4.9	104.9	1.93	3.3	.97	.34	.24	910	2883
FEB	380	548	2598	2978	−1.3	101.3	2.37	3.8	.99	.51	.3	893	2085
MAR	380	518	2455	2835	1.6	98.4	2.42	4.5	1.02	.66	.46	1304	1531
APR	380	301	1427	1807	8.3	91.7	3.54	4.6	1.06	1.1	.65	1175	632
MAY	380	160	758	1138	13.4	86.6	5.30	4.2	1.08	1.6	.85	967	171
JUN	380	67	318	698	17.3	82.7	8.25	4.6	1.10	2.0	1.00	671	0
JUL	380	6	28	408	21.9	78.1	13.3	4.8	1.08	5.1	1.00	408	0
AUG	380	12	57	437	20.8	79.2	12.6	5.1	1.06	5.0	1.00	437	0
SEP	380	122	578	958	15.1	74.9	5.45	5.2	1.02	2.2	.92	881	77
OCT	380	263	1247	1627	9.8	91.2	3.90	4.4	.99	1.1	.65	1058	569
NOV	380	476	2256	2636	2.4	97.6	2.58	3.5	.97	.52	.30	791	1845
DEC	380	640	3034	3414	−2.3	102.3	2.09	2.7	.96	.31	.20	683	2731
YEARLY TOTALS				22,729 kWh/year (15)								10,205 kWh/year (16)	12,524 kWh/year (17)

Annual Solar Fraction = 45 %

Q_W = Water Heating Load = 380 kWh/month

A = Collector Area = 25 m²

B = Heat Exchange Factor = .9

C = Collector Loss Factor = 4.3 W/°C-m²

D = Collector Glazing Factor = .6

L = Building Heat Loss Factor = 4.74 kWh/°C-day

Collector Tilt = 50° degrees

APPENDIX IV: ECONOMIC EVALUATION OF SOLAR SYSTEMS

1.0 INTRODUCTION

Solar radiation is a "free" source of energy but to capture this free energy the user must invest a significant amount of money in solar collection equipment. (A solar system for a residence will cost approximately $7,000 to $15,000.) Once this initial investment is made, yearly energy costs consist of maintenance, taxes, interest and auxiliary energy used during exceptionally cold and cloudy periods. These costs must be compared to the alternative of a conventional heating system and increasing yearly payments for fossil fuels.

Many economic analyses of solar systems are available in government publications and the solar energy literature. Some of the solar design methods reviewed in this Manual include economic analyses as part of the package. For example, one prepared program available for hand programmable calculators (TI-59 or HP-67) includes in its economic analyses: the mortgage period; the mortgage interest rate; the general inflation rate; the insurance rate; the effective federal-state income tax rate; the property tax rate; tax credits; the down payment; the salvage value; the investment tax credit; the period of analyses; the market discount rate; the operating, maintenance, and fuel costs and their rates of increase; the system base cost and the collector costs. Depreciation can be calculated using either declining balance, straight line or sum of year's digits.

All economic analyses depend on predictions of future inflation rates, fossil fuel costs and solar equipment costs. These predictions have a high degree of uncertainty. Further, small changes in the assumed values of these quantities can make dramatic changes in the economic conclusions. There is some consensus of expert opinion on the following important points: (a) Energy cost will increase about 4 to 6% per year above the inflation rate, and (b) Solar equipment costs will probably increase with the inflation rate with only minor possible reductions with mass production.

2.0 A SIMPLE ECONOMIC MODEL

A simple method of economic analysis is presented below for the solar designer who wants to do it himself. This method was developed under a Department of Energy grant by Charles D. Kolstad of Los Alamos Scientific Laboratory.

The analysis utilizes "real dollars" to simplify the calculations. For example: if the inflation rate is 7% and the cost of a solar loan at the bank is 14% the "real interest" is 14% - 7%, or 7%. If you are paying for the solar system with money from your savings account which pays $5\frac{1}{2}$% then the "real interest" for your money is $5\frac{1}{2}$%. Similarly, if fuel costs escalate at 12% overall rate with a 7% inflation rate, the "real" escalation rate of fuel costs is 5% per year. A form for effecting the economic analysis is given in Table 1.

3.0 SAMPLE ECONOMIC ANALYSIS

Assume we wish to install a solar system on a new house. The system will use 15 m^2 of collector and a performance analysis predicts that the system will supply 68% of the annual energy requirement. A heat load analysis predicts an annual requirement of 120×10^9 Joules (120 GJ). The system will cost $10,000. The alternative is to use electric resistance heat. The average cost of power at the site is $0.035/kW-hr (or $9.72/GJ).

The federal tax credit will be $2,200 on this system and the Montana tax credit will be $125. The total tax credit is thus $2325. The bank will loan us the money for the system at 12% for 20 years and the inflation rate is estimated at 7%. This interest is a deduction on our federal taxes, which for our tax bracket reduces the effective interest rate by 1%. These values are entered into the form in Table 2. The sample calculations show that this solar system costing $520/year would be economically competitive with electric heat costing $793/year.

It is suggested that the solar designer go through this economic analysis for several combinations of assumptions of fuel escalation rate and inflation rate.

System cost		A
Tax credit		B
Net system cost		C = A - B
Real interest rate		D
Real fuel escalation rate		E
Tax deduction for interest		F
Net real interest rate		G = D - E - F
Annualized cost		H
Annual maintenance		I
Annual solar cost		J = H + I

Notes:

A. Total installed cost of solar system

B. Federal and state tax deductions (ask tax consultant)

D. Annual interest minus inflation (ask bank for information)

E. Consult expert (about 5%)

F. Depends on your tax bracket (ask tax consultant)

H. Use Tables for Net Cost and Net real interest

I. Usually 1% to 5% of initial cost

K. Use calculated heat load or past fuel bills

L. From solar performance calculations

M. Ask utility company

N. M x 1 for electric heat; M x 1.6 for gas or oil

O. Assuming no solar system is installed

Annual heat load		K
Annual solar heat		L
Current energy cost		M
Net energy cost		N
Annual cost of alternative heat		O = K x N
Annual value of solar heat		P = L x N

(Cost) $/KWh x 278 = (Cost) $/GJ

(Cost) $/$10^6$ BTU * .95 = (Cost) $/GJ

1 x 10^6 BTU = 1.05 GJ

Table 1. ECONOMIC ANALYSIS

$ Annual payment/$1000 loan								
Yrs.	1%	2%	3%	5%	7%	8%	9%	10%
5	206	212	218	231	244	250	257	264
10	106	111	117	129	142	149	156	163
20	55	61	67	80	94	102	110	117
25	45	51	57	71	86	94	102	110
30	39	45	51	65	81	89	97	106
40	30	37	43	58	75	84	93	102
50	26	32	39	55	72	82	91	101

System cost	$10,000	A
Tax credit	$ 2,325	B Fed + State
Net system cost	$ 7,675	C = A − B
Real interest rate	7%	D 14% − 7%
Real fuel escalation rate	5%	E
Tax deduction for interest	1%	F
Net real interest rate	1%	G = D − E − F
Annualized cost	$420	H $55 × 7.675
Annual maintenance	$100	I .01 × $10,000
Annual solar cost	$520	J = H + I

Notes:

A. Total installed cost of solar system

B. Federal and state tax deductions (ask tax consultant)

D. Annual interest minus inflation (ask bank for information)

E. Consult expert (about 5%)

F. Depends on your tax bracket (ask tax consultant)

H. Use Tables for Net Cost and Net real interest

I. Usually 1% to 5% of initial cost

K. Use calculated heat load or past fuel bills

L. From solar performance calculations

M. Ask utility company

N. M x 1 for electric heat; M x 1.6 for gas or oil

O. Assuming no solar system is installed

Annual heat load	120 GJ	K
Annual solar heat	81.6 GJ	L . 68 × 120
Current energy cost	$ 9.72/GJ	M
Net energy cost	$ 9.72/GJ	N M × 1 electric heat
Annual cost of alternative heat	$1166.40	O = K x N 120 × $9.72
Annual value of solar heat	$ 793.15	P = L x N 81.6 × $9.72

(Cost) $/kWh x 278 = (Cost) $/GJ

(Cost) $/$10^6$ BTU * .95 = (Cost) $/GJ

1 x 10^6 BTU = 1.05 GJ

Table 1. ECONOMIC ANALYSIS

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10	106	111	117	129	142	149	156	163
20	55	61	67	80	94	102	110	117
25	45	51	57	71	86	94	102	110
30	39	45	51	65	81	89	97	106
40	30	37	43	58	75	84	93	102
50	26	32	39	55	72	82	91	101

APPENDIX V: CONVERSION IDENTITIES

LENGTH m, 1 meter = 3.2808 feet
1 meter = 39.3701 inches
1 km = 0.62137 miles
1 ft/min = 0.00508 m/s
1 mile/h = 0.44704 m/s
1 km/h = 0.277778 m/s

TEMPERATURE:
$t^{\circ} F = (1.8 \times T^{\circ} C) + 32$
$T^{\circ} C = (t^{\circ} F - 32)/ 1.8$

MASS kg, 1 lb = 0.45359237 kg
1 oz = 28.3495 g
1 lb/ft^3 = 16.0185 kg/m^3
1 lb/h = 0.00012599 kg/s

ENERGY 1 kWh = 3410.08 Btu
1 kWh = 3600 kJ
1 Btu = 2.928×10^{-4} kWh
1 Btu = 1.0548 kJ
1 Btu = 0.251996 kcal
1 Btu = 10^{-5} therm
1 Btu = 10^{-15} quad

POWER 1 kW = 3414.43 Btu/h
1 kW = 56.8253 Btu/min
1 kW = 238.662 cal/sec
1 Btu/h = 2.931×10^{-4} kW
1 Btu/h = 0.01667 Btu/min
1 Btu/h = 0.0700 cal/sec
1 Btu/h = 3.9275×10^{-4} hp

AREA m^2, 1 m^2 = 10.7639 ft^2
1 m^2 = 1550 in^2
1 km^2 = 0.3860 $mile^2$
1 km^2 = 247.105 acres

VOLUME m^3, 1 ft^3 = 28.3168 liters
1 U.S.gal = 3.78544 liters
1 ft^3/lb = 0.062428 m^3/kg
1 cfm = 0.471947 liter/s
1 U.S. gpm = 0.0630907 liter/s

FORCE newton N, 1 lbf = 4.44822 N
1 psi = 6.89476 kPA
1 in H_2O = 249.089 Pa
1 atm = 101.325 kPa

ENERGY DENSITY 1 kWh/m^2 = 316.815 Btu/ft^2
1 kWh/m^2 = 3600 kJ/m^2
1 kWh/m^2 = 360 J/cm^2
1 kWh/m^2 = 85.933 cal/cm^2 (langley)
1 Btu/ft^2 = 3.1517×10^{-3} kWh/m^2
1 Btu/ft^2 = 11.3538 kJ/m^2
1 Btu/ft^2 = 1.13538 J/cm^2
1 Btu/ft^2 = 0.27125 cal/cm^2 (langley)

POWER DENSITY 1 kW/m^2 = 317.21 Btu/ft^2-h
1 kW/m^2 = 3600 kJ/m^2-h
1 kW/m^2 = 0.1 W/cm^2
1 kW/m^2 = 0.23901 langley/sec
1 kW/m^2 = 14.3406 langley/sec
1 Btu/ft^2-h = 3.1524 W/m^2
1 Btu/ft^2-h = 11,348 kJ/m^2-h
1 Btu/ft^2-h = 3.1524×10^{-4} W/cm^2
1 Btu/ft^2-h = 7.5347×10^{-5} langley/sec
1 Btu/ft^2-h = 4.5208×10^{-3} langley/min

The following prefixes are recommended for use with SI units:

tera T 10^{12}, giga G 10^{9}

mega M 10^{6}, kilo k 10^{3}

milli m 10^{-3}, micro 10^{-6}

nano n 10^{-9}, pico p 10^{-12}

SOME PROPERTIES IN SI UNITS

Density (kg/m^3)

Copper	8795
Steel	7850
Aluminum	2675
Glass, standard	2515
Concrete, typical, building	2400
Water, 4° C	1000
Ice, -1° C	918
Gypsum plaster, dry, 23° C	881
Oak, 14% wet	770
Pine, 15% wet	570
Pine fiberboard, 24°C	256
Asbestos cement, sheet, 30° C	150
Cork board, dry, 18° C	144
Ebonite, expanded, 10° C	64
Mineral wool, batts, -2°C	32
Polyurethane, foam, rigid	24
Polystyrene, expanded, 10° C	16
Air, p_o, 20° C	1.204

Heat of vaporization (kJ/kg)

Water, 20° C	2454.0
Water, 100° C	2257.0

Thermal conductivity (W/m° C)

Copper	385
Aluminum	211
Steel	47.6
Ice, -1° C	2.26
Concrete, typical, building	1.73
Glass, standard	1.05
Water, 20° C	0.596
Asbestos cement, sheet, 30° C	0.319
Gypsum plaster, dry, 23°C	1.170
Oak, 14% wet	0.160
Pine, 15% wet	0.138
Pine fiberboard, 24° C	0.051
Cork board, dry, 18° C	0.041
Mineral wool, batts, -2° C	0.034
Polystyrene, expanded, 10° C	0.034
Ebonite, expanded, 10°C	0.030
Air, p_o, 20° C	0.026
Polyurethane, foam, rigid	0.024

Specific heat (kJ/kg° C)

Water, 20° C, p_o	4.19
Ice, -21° C to -1° C	2.10
Steam (c_p), 100° C, p_o	1.95
Air (c_p), 20° C, p_o	1.012
Concrete, 18° C	0.837

Standard gravity g_o: $g_o = 9.80665$ m/s

Gas constants:

$R_u = 8314.4$ J/kmol K universal

$R_a = 287.045$ J/kg K air

Stefan-Boltzmann constant:

$$\sigma = 5.6697 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$$

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